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JOHNS HOPKINS UNIVERSITY,

BALTIMORE, MD.

CHESAPEAKE

ZOÖLOGICAL LABORATORY.

SCIENTIFIC RESULTS

OF THE

Session of 1878.

(June 24th to August 19th, 1878.)

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JOHNS HOPKINS UNIVERSITY,

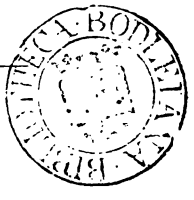
BALTIMORE, MD.

CHESAPEAKE

ZOÖLOGICAL LABORATORY.

ORGANIZED AND CONDUCTED

BY W. K. BROOKS.



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While I have received most cordial responses from all to whom I have applied for help in the present undertaking, my thanks are especially due

ERRATA AND CORRECTIONS.

The paper by Mr. Rice, on the "Early Stages of Amphioxus," has been delayed by the sickness of the author. It will be printed elsewhere at an early date.

On page 35, line 9 from top, *for* Mr. Crady, *read* McCrady.
" 36, " 10 " " " Mr. Crady, " McCrady.
" 85, bottom line, *for* Terebratulina, *read* Terebratula.
" 94, " " *for* ontogenetic, *read* phylogenetic.
" 95, line 4 from top, *for* ontogenetic, *read* phylogenetic.
" 112, " 17 " " " Mouth cavity, *read* Mantle-cavity.
" 113, " 1 " " " Typus, *read* typus.
" 116, " 6 " bottom, *for* J. R., *read* J. V.
" 116, " 4 " " " Regnaudii, *read Reynaudii*.
" 117, " 6 " top, *for* S. J., *read* S. I.
" 117, " 6 " bottom, *for* Heusen, *read* Hensen.
" 118, " 6 " " *for* Erforshung, *read* Erforschung.
" 119, " 2 " " *for* objection, *read* objective.
" 144, " 19 " top, *for* Plates 4 and 5, *read* Plates 12 and 13.

W. K. BROOKS, PH. D., *Associate in Biology*,
JOHNS HOPKINS UNIVERSITY,
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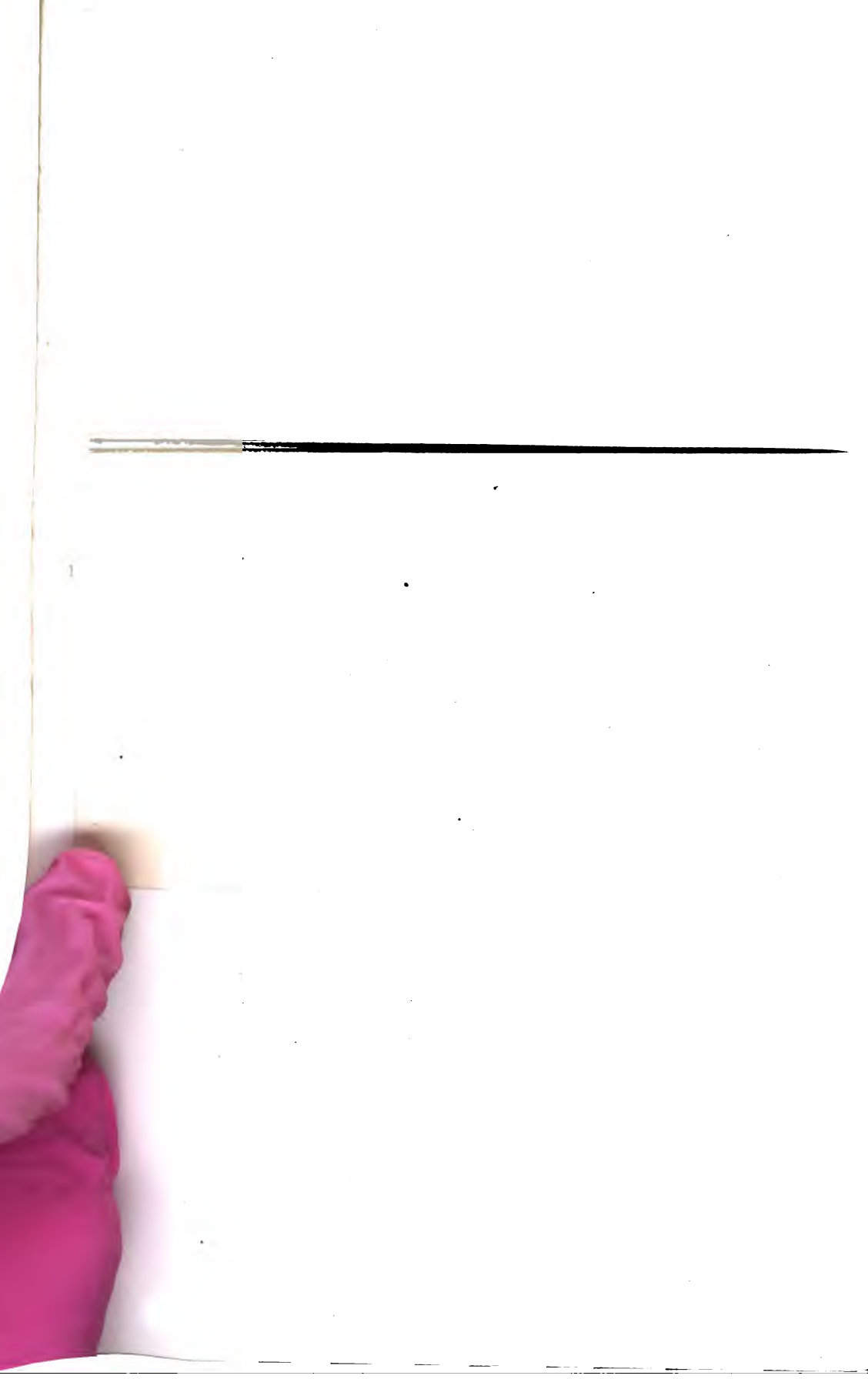

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To THE HONORABLE THE SECRETARY OF WAR, and to MAJ. GEN. Q. A. GILMORE, U. S. A., for the use of Government buildings at Fort Wool.

To SPENCER F. BAIRD, U. S FISH COMMISSIONER, and to T. B. FERGUSON, FISH COMMISSIONER OF MARYLAND, for valuable assistance.

To S. M. SHOEMAKER, ENOCH PRATT, J. W. GARRETT, J. W. MCCOY, and other Citizens of Baltimore, for the funds to publish this Report.

To THE TRUSTEES OF THE JOHNS HOPKINS UNIVERSITY for their liberal interest and assistance in a project which has not heretofore been regarded as within the province of an educational institution.

W. K. BROOKS, PH. D., *Associate in Biology*,
JOHNS HOPKINS UNIVERSITY,
BALTIMORE, MD.

INTRODUCTORY.

THE Trustees of the Johns Hopkins University having consented to the establishment, as a branch of the biological department of the University, of an experimental sea-side laboratory for the study of the marine zoölogy of the Chesapeake Bay, I visited the lower part of the bay in April, 1878, in order to select the best place for the experiment. Owing to the unhealthfulness of the shores of the bay, near the Capes, and the absence of suitable buildings, I was compelled to select a point at a considerable distance from the ocean, and the best point for the first attempt appeared to be the incompleted fortification known as Fort Wool. This fort is situated in the mouth of Hampton Roads, about one mile and a half from one shore, and three miles from the other, and about twenty miles from the ocean. It is an artificial island made by dropping granite rocks into the water, thus elevating an area of about six acres above high tide level. The area of six acres is almost covered by the incompleted fortification and building material, and the available space is thus reduced to about half an acre. In this space are two large frame

buildings, well lighted, near the water, and well adapted for use as a laboratory. Application was accordingly made, near the end of April, to Major Gen. Q. A. Gilmore, the officer in charge of the property, for permission to occupy them for the summer for that purpose. Through the kindness of the late Professor Henry and of Professor Baird, the Secretary of War was also informed in regard to the nature of the project, and on May 22d, the desired permission was received, and the following circular issued:

JOHNS HOPKINS UNIVERSITY.

CHESAPEAKE ZOÖLOGICAL LABORATORY.

A seaside laboratory for the study of marine zoölogy will be organized at Fort Wool, near Old Point Comfort, Va , during the present summer, as one of the departments of the Johns Hopkins University, and will be open for students on Tuesday, June 25th, 1878.

As the laboratory is especially designed to facilitate the researches of advanced scientific workers, no courses of lectures will be announced. There will, however, be an opportunity for a few less advanced workers, especially teachers, either ladies or gentlemen, to profit by the facilities which the laboratory will afford for collecting and observing marine animals, and such students will also receive proper help and guidance from those engaged in advanced work.

An efficient steward has agreed to superintend the table, and the price of board will not exceed five dollars ($5.00) per week.

A fee of ten dollars ($10 00) will be charged by the University for the use of the laboratory outfit during the season.

As the lodging rooms at the Fort are unfurnished, each student must provide all necessary bed-room furniture.

There will be daily communication during the summer with the Post Office at Old Point Comfort, and those who wish, will be able to lodge at the hotel

The necessary outfit was then provided, and the laboratory was opened at Fort Wool, on Monday

the 24th of June, 1878, and was occupied until Monday, August 19th, or eight weeks. Owing to the unavoidable postponement of the announcement until so short a time before the opening, the number of applicants was quite small, and many persons who would have been glad to join the party were prevented by other plans which they had formed for the summer.

The following is a list of the scientific students of the party:

W. K. BROOKS, *Associate in Biology, Johns Hopkins University; in charge of the Laboratory.*
P. R UHLER, *Associate in Biology, Johns Hopkins University.*
H. SEWALL, *Fellow, Johns Hopkins University*
CHR. SIHLER, M. D., *Fellow, Johns Hopkins University.*
H. J. RICE, " " " "
AUGUST SCHMIDT, *Teacher of Nat. Science, Zion School, Baltimore.*
N. B. WEBSTER, *Principal Webster Military Academy, Norfolk, Va.*
T. B WEBSTER, M. D., " " " " "
MRS. N B. WEBSTER, " " " " "
W. R. BOOKER, M. D., *Baltimore, Md.*

The laboratory was designed to accomplish four objects: to furnish advanced students with opportunities for original investigation; to provide material for winter work in the University; to enable less advanced students to become acquainted with the many forms of life which can only be studied at the sea-shore, and to give them an opportunity to become practically acquainted with the methods of marine zoölogical work; and to increase our scientific acquaintance with the zoölogy of the Chesapeake Bay.

The opportunities for advanced work in the study of invertebrate embryology were all that could be desired, and we had an unfailing supply of the most interesting material within our reach at all times. A strong current runs close to the walls of the fort, and thus carries a great body of water,—fifteen or twenty miles—past its walls at each turn of the tide, and free swimming animals and embryos and locomotive larvae could be obtained in endless variety without leaving the fort. The waters are especially rich in crustacean and anellidan larvae, and for work upon these groups at the station, it furnishes unrivalled advantages. Among the interesting forms of life which were most abundant, I may mention Sagitta, Appendicularia, Torinaria and Balanoglossus, Pilidium, Actinotrocha, and other important trochic larvae, Squilla and Porcellana in all stages of development, Amphioxus at all stages, and other forms of equal scientific importance. An abundant supply of material for work upon the adult structure and development of the Sponges, Hydroids, Medusae, Ctenophorae, Gephyreans, Anellids, Crustacea, Tunicata, Polyzoa, Brachiopods, Lamellibranchs, Gasteropods, and lower Vertebrates, is within easy reach. We found very few Echinoderms, and only one Cephalopod, but these groups could no doubt be found more abundantly by dredging nearer the mouth of the bay. We

collected near the fort, representatives of the Echini, Starfishes, Ophiourians and Holothurians, but not in abundance; and we found no Echinoderm larvae.

This list will show that there is ample opportunity for the less advanced student to become acquainted with marine life, and although no lectures were given, the students had free access to a very good collection of books on marine zoölogy and the proper reading to be done in connection with the study of each form of life was pointed out by the Associate in charge of the laboratory.

These students had the benefit of all distant excursions, and were thus enabled to become familiar with the methods of deep water and shore collecting, and to acquire familiarity with the habits of marine animals while gathering the material for more careful study in the laboratory. Here each student had ample room for dissection and for microscopic work, as well as the facilities for keeping and observing living animals in aquaria.

The following papers give an account of some of the scientific results of the first summer's work, and from them naturalists will be able to judge for themselves as to the advantages which the station offers for original investigation. As the main object of the laboratory is to furnish ad-

vanced workers with opportunities and facilities for carrying on their studies at the sea-shore, its future will depend upon the number of such persons who wish to make use of it. While it is to be hoped that there are at the present time enough persons engaged in morphological and embryological work in this country to make the want which the laboratory aims to meet a real one, this can only be ascertained by experiment. I have entitled the following papers the "Scientific Results" of the first session, but all who have been engaged in similar work know that only a very few of the subjects which are investigated can be carried sufficiently far in a single season to make their publication desirable. In addition to the subjects treated in the following papers, many other investigations were carried sufficiently far to yield interesting results, but their completion and publication must be delayed until favorable opportunities again present themselves.

A great part of our time was devoted to the collection and study of the microscopic embryos and larvae of the various forms of marine life, and as those who are not familiar with this department of zoölogy may be interested in hearing how animals too small to be examined without a microscope are collected in the open ocean, a short account of our methods will not be out of place

here. Nearly all marine animals discharge their eggs, in very great numbers, into the water, and the young are left to provide for themselves, and whether the adults are swimming animals or those which live at the bottom, or those whose proper habitat is along the shores and marshes or those which are fastened to one spot like the barnicle and the oyster, the young are, in nearly every case, fitted for swimming, and during this wandering period of their lives are diffused over a great extent of water by the tides and currents. They seldom bear any very close resemblance to their parents, and frequently undergo the most remarkable transformations before they reach the adult form. During the day and in rough weather they are scattered at a distance below the surface of the water, but on calm nights they come to the surface in inconceivable abundance, and may then be gathered by a method known as surface collecting, which is the very poetry of life at the sea-shore, although it is useless to attempt to describe the charm and fascination of midnight work in a small boat upon the calm surface of the ocean in the perfect quiet of an August night. About an hour after dark, on a summer evening, as the evening breeze dies away the water begins to grow phosphorescent, and the swell breaks upon the shore in lines of light. As the smaller animals accumulate at the surface the light grows more

brilliant and about ten o'clock, if the evening is a favorable one for surface collecting, the water, when disturbed by oar or net, is filled with star-like sparks, each one of which is an organism.

At the proper time a party of two push off into the darkness in a small boat, and guiding themselves by the light in the water, find a spot where an eddy or current has brought great numbers of animals together. The collecting apparatus consists of a bucket nearly filled with sea water, and a short handled net, about six inches in diameter and two inches deep, made of bolting cloth, or of a finely woven silk veil. As this net is gently moved through the water, the animals adhere to it, and its surface flashes out into a brilliant glow, as if it had been heated to redness. After two or three gentle dips it is raised and inverted over the bucket of water, and the sparks washed off, and the process repeated. After an hour or more of collecting, the bucket of water is carried home for examination. At the laboratory, a lighted lamp is placed in the centre of a table, and tall jars or ale glasses are filled with water from the bucket, and held up before the light for examination. If the collecting has been very good the water will be found to be crowded with small living animals so that the light can hardly penetrate it, and the bucket must be diluted with another of ordinary sea water before it can be examined. When this

is done each glass will be found to contain strange organisms in sufficient variety to furnish the material for weeks of study. As the water slowly circulates around the glass, carrying the various animals past the eye, it presents an indescribable shifting panorama of strange, grotesque and beautiful animals, most of them perfectly transparent, and varying in size from those too small to be seen without a lens, to those half an inch long. Nearly every glass contains small hydro-medusae expanding and contracting their transparent bells and slowly rising and sinking in the water; young Ctenophorae with irridescent zones of steel blue, and green and purple flashing over their bodies; the transparent embryos of fishes, their large black staring eyes and golden yolk sacks attracting the eye, although their shadow like bodies are scarcely visible. Numerous veliger embryos of various Mollusks are usually to be seen, expanding their transparent sails, and rising slowly to the surface by the beating of their irridescent cilia, and then darting back into their shells and sinking slowly to the bottom. Occasionally an Amphioxus embryo starts up from the bottom of the vessel, and after darting from side to side, stiffens and sinks again to the bottom, while an endless variety of grotesque crustacean embryos dart vigorously in all directions. Resisting the temptation to examine all the novel forms which attract his eye, each student

catches with a dipping tube the animals upon which he is working at the time, and places them in watch crystals, tumblers or small jars, with fresh sea water, in order to preserve them for his work.

As regards the number and variety of forms found by surface collecting, Fort Wool is superior to any other locality with which I am acquainted.

The accompanying papers give some of the scientific results of our work, but as they are written to be read by specialists, I will try to give a brief statement of some of the more interesting points, for the benefit of the unscientific friends who have aided in the organization and management of the laboratory and in the publication of the papers.

The lists of animals and plants found at Fort Wool, by Prof. Uhler and Prof. Webster, are by no means complete, but they are of great interest, as showing the rapidity with which land animals and plants gain access to an isolated spot. Although the fort is simply a pile of rocks, with only such soil as was made by the chips of the stone cutters, the list of land animals and plants which have gained a footing there is quite extensive. It is interesting to note also that although the period during which these forms have been isolated is quite short, less than twenty years, Prof. Uhler has found one case, the Cricket, in

which the form at Fort Wool is a well marked variation.

The paper by Mr. Rice, upon Amphioxus, is one of especial interest, as Amphioxus is the lowest representative of the group Vertebrate, which includes all the higher animals and man.

Amphioxus is a small worm-like animal, without a skeleton or hard parts, and with the brain almost wanting, and without eyes or other sense organs. It lives in the sand at the bottom of rather shallow water, and while it agrees with the higher vertebrates in so many points, that its relation to them is undoubted, it is very much simpler in organization than many of the invertebrates.

A thorough knowledge of every thing which relates to its structure, habits and development, is of great scientific value, as it is the key to a correct knowledge of the higher vertebrates; the generalized diagram or abstraction of the group Vertebrata as a whole. It has been very thoroughly studied by European zoölogists, and numerous papers upon it have been published within the last few years, and Mr. Rice has been able to supplement these observations, and to supply facts which render our acquaintance with it more complete. During the past year, Amphioxus has been found in the Bermudas, and it has also been found upon the coast of North

Carolina, but previous to the past summer these were the only places where it was known to exist upon this side of the Atlantic. Our discovery of it in the Chesapeake Bay, renders it accessible to any American Naturalists who may wish to study it.

Although there is no doubt that many of the lower animals which are found in the Chesapeake Bay have never been described by Naturalists, we made no attempt to discover and describe new species. This work can be thoroughly and satisfactorily done only at places where large collections and libraries are accessible, and it is more properly *museum* than *laboratory* work; while a sea-side laboratory furnishes opportunities for work of a different character, which cannot well be carried on in museums; the study of the structure, development and habits of animals as living things. We accordingly tried to study a few forms thoroughly, instead of searching for novelties. In our collecting, we met with many species which there is reason to believe are new, and these were preserved, and descriptions of such as prove to be new will be published after they have been properly studied.

During the latter part of the session, Mr. Schmidt, one of the students of the party, collected a few specimens of a small crustacean of the genus Leucifer, and as not only the species, but the genus

is new to American waters, I sent one of the specimens to Prof. Walter Faxon, of Harvard College, a specialist in that department, and he has prepared an illustrated description which forms part of this report.

I hope that my own principal contribution to the report, "The Development of Lingula," is not without scientific value. Lingula is a small animal which is found as a fossil in almost the earliest fossiliferous rocks, and has been in existence ever since, and is found in geological formations of all ages. It is a very remarkable exception to the general law that forms of life, like individuals, have a limited duration, which, geologically speaking, is quite short. As far as we have evidence it is the oldest animal now living, and almost the earliest which is found as a fossil. It is a small animal, composed of a fleshy cylindrical stem or root, about two inches long, and at the end of the stem a pair of horny tongue-shaped shells, between which the body is placed. It lives in the sand, in from one to ten fathoms of water, with its stem buried in the sand, and the tip of the shell projecting. The mouth, which is between the two shells, is surrounded by a crown of several hundred arms, which are covered by microscopic hairs or cilia. These cilia are in constant motion and cause currents in the water, and by these currents small plants are continually swept into the animal's

mouth. Its long duration is to be explained, perhaps, by the great simplicity of its conditions of life, for ever since the sedimentary rocks began to be formed, banks of sand must have existed in some part of the ocean. The horny shell of Lingula is quite tough, and easily preserved, and the animal lives in the proper situation for being readily preserved as a fossil. While there are undoubtedly other animals which have existed for as long a time we have no record of their existence, as their remains have not been preserved in the rocks.

It will readily be understood that a thorough knowledge of every thing relating to Lingula is of importance in the study of the laws according to which living things have been produced, and I regard the observations which I was able to make upon its development, as among the most important results of our summer's work.

W. K. BROOKS,
Associate in Biology,
Johns Hopkins University.

Partial List of the Land Plants found at Fort Wool.

By N. B. Webster, *Norfolk, Virginia.*

The flora of the six-acre pile of granite rocks, rendered dear to the memory of the members of the Chesapeake Zoölogical Laboratory by their pleasant summer residence there, is interesting, as showing what plants gain a home on almost soilless, barren rock and its detritus.

It is not probable that any of them were *purposely* introduced, but that seeds were carried by birds, wafted by winds or waves, conveyed in hay, straw, or packing materials, or incidentally scattered by soldiers or visitors who threw away peach kernels, &c., among the rocks. Not less than fifty species of plants grow luxuriantly on the island, many of which I had no opportunity to determine.

Arenaria serpyllifolia. Thyme-leaved sandwort.
Aristida dichotoma. Beard grass.
Ambrosia artemisiæfolia. Hog-weed.
Baccharis halimifolia. Sea-groundsel tree.

Capsella bursa-pastoris. Shepherd's purse.
Cyperus echinatus. A common sedge.
Dactylis glomerata. Orchard grass.
Ficus carica. Common fig, growing under difficulties without much earth. Leaves tough and deeply incised. No fruit.
Fragaria vesca. Strawberry.
Juniperus Virginiana. Red cedar.
Linaria vulgaris. Butter and eggs.
Melilotus alba. Sweet clover.
Maruta cotula. May-weed.
Opuntia vulgaris. Prickly pear.
Oenothera biennis. Evening primrose.
Phytolacca decandra. Pokeberry.
Persica vulgaris. Peach.
Portulacca oleracea. Purslain.
Polypogon Mouspeliensis. Polypog grass.
Poa pratensis. June Spear-grass.
Rumex crispus. Curled dock.
Rubus strigosus. Red raspberry.
Rubus villosus. Blackberry.

List of Animals observed at Fort Wool, Va.

By P. R. Uhler.

A residence of about one week, in August, at the Chesapeake Biological Laboratory enabled me to make a list of such creatures as occurred there and in the adjacent waters at that time. This list is of course very incomplete and omits whole groups of objects which might have been found there either earlier or later in the season.

Each year has its peculiar forms in such localities; and so a period of several years of close observation would be required to secure a tolerably full catalogue of the genera and species belonging to the region.

As this island is an artificial one, with only a slight layer of soil upon the surface of large blocks of stone, covering an area of less than six acres, but little can grow to sustain life, and every kind of creature found thereon has been brought from some other locality. Yet, many forms of life are indigenous to the surrounding waters, and a fine harvest of them may be gathered at most times upon and between the rocks forming the outer boundary.

The place is conspicuous for the absence of most things belonging to fresh water, and hence the Dragon flies and other insects dependant upon that element in their young stages must come from the not distant mainland.

The submerged rocks and adjacent waters are well stocked with Mollusks, Crustacea, Bryozoa, Hydroids, and various Sponges and Sea-Weeds, and around the wharf Fish of several kinds may readily be taken with the hook and line.

MOLLUSCA.

CEPHALOPODA.

Loligo punctata, Dekay.

Occasionally captured in seines and trawl nets, and a few have been taken in autumn from the stomachs of Blue fish, *Pomatomus saltatrix*, Linn.

GASTROPODA.

Bela plicata, Adams.

Obtained by dredging on muddy bottom a few rods from the Fort.

Sycotypus canaliculatus, Gill.

On muddy sand in shallow water. It lives in many parts of Chesapeake Bay, where the water is very salt, and where mud flats extend out

from the shores. On the Atlantic coast of Virginia and Maryland it is very common near and in the muddy inlets and around the islands.

Ilyanassa obsoleta, Stimpson.

Common in shallow places where the bottom is mixed sand and mud.

Urosalpinx cinerea, Stimpson.

Very common on the rocks below high water mark. It was very variable in size and in thickness of the shell. The larger specimens were often observed to be coated with sponge, cases of Serpula, barnacles and sea-weed, and this was particularly the case with dead specimens which stuck in crevices of the rocks.

Eupleura caudata, Adams.

Dredged in shallow water on sandy bottom, mixed with mud.

Lunatia heros, Adams.

Common in deeper water near Fortress Monroe, and obtained by dredging.

Neverita duplicata, Stimpson.

Very common on sandy bottoms. It grows to a very large size in this region, as it does also in many places near the entrance to Chesapeake Bay, and in the adjoining Ocean.

Crepidula plana, Say.

Found sticking to shells and among oyster rubbish on slightly muddy bottoms.

Crepidula fornicata, Say, (Lamarck?)

Quite common among oysters, and often found adhering to their shells. Met with in several places between the rocks on the outside of the Fort, below low water mark.

Crucibulum striatum, Adams.

Dredged in places where broken shells and rubbish abounded, in water about eight fathoms deep.

Littorina irrorata, Gray.

Extremely common on the rocks and in the ditches within the fortification. It abounds on the Eel-Grass and upon water plants of the fresh and salt marshes of both shores of Chesapeake Bay.

CHITONIDAE.

Chiton cinereus, Linn.

Found upon the shell of an oyster dredged in ten fathoms depth. It is quite common on oysters and other shells along the Atlantic coast of Northampton county, Virginia. No reddish specimens have thus far been reported from the region of Virginia.

NUDIBRANCHIATA.

Doris bilamellata, Linn.

Two specimens and eggs were found by Dr. Christian Sihler, in tide pools beneath the wharf. The identification of this species may not be strictly accurate; but from the appearance, size and form of the specimens they approach nearest to that here given.

LAMELLIBRANCHIATA.

Teredo navalis, Linn.

Broken shells of this creature occur among the rubbish at the bottom of the water. It is common in the Elizabeth River, and will no doubt be found in the submerged parts of the piles which support the wharf.

Petricola pholadiformis, Lamarck.

Occurs in muddy places in shallow water. It is quite common in the inlets adjoining the mouth of Chesapeake Bay, and in company with a very small form of another genus may be found imbedded in the hard clay of the shallow oyster beds.

Mya arenaria, Linn.

In muddy sand along the margins of both shores of Virginia, also near Fort Monroe, and along

the Atlantic shores of the Eastern Shore of Maryland and Virginia. It is also found at the mouths of rivers on both sides of nearly the whole extent of Chesapeake Bay.

Cochlodesma Leanum, Couthoy.

Single valves occurred among the broken shells dredged from sandy and mixed bottoms.

Ensatella Americana, Verrill.

In the muddy sand along the shores of Virginia, Maryland, &c. Odd valves and fragments of this razor-shell were dredged a few rods from the Fort.

Macoma fusca, Adams.

Common in dark oyster mud in shallow water.

Solen viridis, Say.

A few young specimens were dredged at various distances from the wharf. They were generally from a muddy sandy bottom.

Mulinia lateralis, Gray.

Dredged at various points in water from five to ten fathoms in depth.

Venus mercenaria, Linn.

Quite abundant on muddy beds in shallow water and along both coasts of the Chesapeake, in Southern Maryland and Virginia.

A young clam with concentric elevated ridges was dredged in five to ten fathoms on sandy bottoms. It conforms pretty nearly with the figure of *Mercenaria* fulgurans Tryon, Amer.

Marine Conchol. pl. 27, No. 391, but is smaller, probably younger, and lacks the zigzag lines there given.

Mactra ovalis, Gould.

In sandy places at moderate depths and on sand-bars. Young specimens brought up by the dredge at various points.

Yoldia limatula, Stimpson.

Small specimens mixed with the fragments of other shells, were brought up from pasty mud by the dredge. They are less than one-half the size of those found on the coast of New England, and may prove to be specifically distinct. A similar, if not identical form, lives well buried in the sticky mud of the Patapsco, and other rivers of our Western Shore of Maryland.

Arca ponderosa, Say.

Dredged from sandy bottoms, mixed with mud, in water eight to ten fathoms deep. It is moderately common in the Ocean, off the coast of Northampton County, Va., in holes fifteen to twenty fathoms in depth. At Assateague inlet, it may be dredged from the deeper water in the mouth of the channel, in company with the succeeding species.

Arca Americana, Gray.

Specimens of medium size occur in the same places as the preceding. Both of these forms

are covered with a hispid blackish coat, which is rarely found intact, and which gives them the appearance of being wrapped in woolen plush.

Modiola plicatula, Lamarck.

Found adhering to oysters, and wedged between rocks, particularly where mud has settled. It is distributed over most parts of Chesapeake Bay, south of Tangier Sound, and abounds in the adjoining Ocean wherever oyster beds have place.

Modiola modiolus, Turton.

Common between the rocks and on oyster bars in muddy places. Very abundant on the Atlantic coast of Maryland and Virginia.

Anomia glabra, Verrill.

Dredged in many places near the Fort, and some specimens were found attached to the rocks near and beneath the wharf; also on oysters.

Ostrea Virginiana, Lister.

Quite numerously attached to the rocks on the Western and Northern sides of the island. It is of the form common to York River, and vicinity of the mouth of James River. A few specimens may be selected which show the scalloped edges and ridged surface of the typical form of the Eastern side of Chesapeake Bay. A third form, resembling the round, small, deep shells of the Raritan River, inhabits the bars in the tidal part and mouth of the Patuxent River.

CRUSTACEA.

BRACHYURA.

Ocypoda arenaria, Say.

Not found upon the island, but may be collected on the sandy shore near Fort Monroe.

Gelasimus pugilator, Lat.

Common on the adjacent shores, particularly near Fort Monroe. At the latter place it occurs in countless numbers upon the muddy sand flats, in company with another species not determined.

Pinnotheres ostreum, Say.

Occasional in oysters.

Panopaeus depressus, Smith.

In muddy places and among the oysters in shallow water.

Platyonichus ocellatus, Lat.

Moderately common in the sand not remote from shore; and occasionally dug out by the dredge in shallow places.

Neptunus hastatus, Milne-Edw. (Say).

Very abundant near the wharf, and very generally distributed throughout Chesapeake Bay and along the Atlantic coast. It breeds and develops in this vicinity.

ANOMOURA.

Hippa talpoida, Say.

Common in sandy places near the adjacent shores. The young ones may be found around the edges of the island.

Eupagurus, sp.?

Two forms of these Soldier Crabs inhabit shells of mollusks, among the rocks and on the bottom around the island; but the species have not yet been determined.

MACROURA.

Crangon vulgaris, Fab.

Occurs around the rocks near the wharf.

Palæmonetes vulgaris, Stimpson.

This is the common Shrimp of Chesapeake Bay, and it may be found almost everywhere in shallow water.

AMPHIPODA.

Gammarus, sp.?

In rubbish and sea-weed between the rocks near the wharf.

Caprella geometrica, Say.

Common in the water near the wharf and among the Bladder-wrack growing on the rocks; but

extremely abundant inside of the oscules of a roundish form of sponge common to that vicinity.

ISOPODA.

Livoneca ovalis, Harger.

Taken from the gills of a Croaker fish caught at the wharf.

CIRRIPEDIA.

Adhering to the piles of the wharf in moderate numbers, and not uncommon on the rocks and on shells of Mollusks.

ANNELIDA.

Nereis, sp.?

Common in muddy places and upon oysters.

Other Annelids occur in the water around the Fort, but the species have not yet been determined.

RADIATA.

One or more *Holothurians*, an *Asterias* and an *Ophiopholis* may be dredged from the water in the near vicinity; but their names have not yet been determined.

As I am in doubt as to the names of the *Bryozoa*, *Acalephs* and *Hydroids* common to the rocks and waters around the island, they must be left unrecorded at present.

SPONGOZOA.

Microciona prolifera, Verrill.

Quite common on oysters, and also to be found adhering to rocks beneath the wharf.

This species of Sponge harbors *Paramecium;* and by placing a piece of it in a vessel of water, countless swarms of these little creatures may be seen streaming forth in all directions.

INSECTA.

LEPIDOPTERA.

Vanessa (*Grapta*) *interrogationis*, Fab.

One specimen seen flying around the wooden barracks.

Papilio troilus, Linn.

Three specimens were observed flying over the flowers of *Miliola.*

Papilio asterias, Fab.

One specimen with damaged wings seen flying about the tall weeds.

Danais archippus, Fab.

Several specimens seen flying vigorously over the island, and occasionally alighting upon the taller weeds.

Utetheisa bella, Pack.

Two or three specimens were aroused in the thickest patches of weeds.

Three or four species of small Moths were seen; but they were too imperfect for identification.

COLEOPTERA.

Cicindela punctulata, Fab.

Quite common in the paths, and all the specimens noticed were of the dull black variety.

Pangus caliginosus, Fab.

Only two specimens seen. They were crawling about in the midst of the weeds and rubbish.

Harpalus bicolor, Fab.

Common beneath loose stones and rubbish.

Stenolophus plebeius, Dej.

Found beneath loose stones and rubbish; not common.

Cercyon prætextatum, Say.

Seen pushing its way among loose rubbish, next the ground.

Collops quadrimaculatus, Fab.

On various bushes and weeds; quite common.

Diabrotica 12-punctata, Oliv.

Common on *Baccharis* and other bushes.

HYMENOPTERA.

Apis mellifica, Linn.

Seen flying over the flowers of weeds.

Bombus of three species, not identified.

Xylocopa Virginica, Fab.

Two or three specimens were noticed flying about the windows of the wooden houses.

Polistes Canadensis, Fab.

The dark brown variety is common on *Baccharis* and other bushes.

Stizus grandis, Linn.

Solitary specimens seen alighting on the bare ground.

Bembex of two species noticed on the rocky soil.

Odynerus, sp?

Seen on the twigs of *Baccharis*.

Formica. A black species, not identified.

Myrmica. Likewise not identified.

Several forms of the group *Ichneumonidae* were noticed, but not collected nor determined.

ORTHOPTERA.

Gryllus luctuosus, Serv.

This lively black cricket is quite common among the large fragments of rock, in the cracks between which it hides and finds shelter. All the specimens seen, of both sexes, had the wings very long.

The wing-covers were brown, but not so pale as in the specimens found on the sea-coast. Heat, moisture, a mild climate during most of the year, abundance of food and protection enable this insect to perfect all its organs to the utmost extent.

Oedipoda eucerata, Harris.

The red-winged variety may be found in bare spots where the rocks have been reduced to sand.

Oedipoda carolina, Burm.

Quite common all over the island; as well upon the rocks as upon the soil. It is interesting to notice how well these specimens match the dark granite amidst which they live. By close attention one may readily predict the color of the soil from which this species has been taken. On the red-sandstone soils it is of that color, on the black loams it is very dark, and upon the yellow clay soils it is of the latter color.

It does not, however, become sand-colored when found on the sandy beaches; but we have no evidence that it ever lays eggs or hatches in such places.

Caloptenus femur-rubrum, Burm.

Moderately common among the weeds.

Caloptenus differentialis, Thomas.

One specimen seen and captured.

NEUROPTERA.

Epitheca filosa, Hagen.

Several specimens were flying and gracefully balancing themselves in the air along the case-mates. The females had wings tinged with a large clear fuscous cloud towards their tips.

Tramea carolina, Hagen.

Two or three examples seen early in the morning flying over the weeds.

Celithemis eponina, Hagen.

Not common. Seen on the tops of bushes and tall weeds.

Libellula auripennis, Burm.

Very common. The larvae inhabit brackish pools and ditches in the salt marshes.

Libellula quadrupla, Say.

A few specimens were caught while they were flying over the rocks and in some cases settling upon them.

Libellula pulchella, Drury.

This species seems to prefer the prominent rocks and casemates as points upon which to settle and rest.

Libellula semifasciata, Burm.

Several specimens were captured on the tops of the tall weeds.

Dythemis longipennis, Hagen.

Very common upon bushes and plants. It proved to be quite variable both in size and color. The males were much more numerous than the females, and they were usually much coated with the blue powder present upon the abdomen when fully matured.

Diplax Berenice, Drury.

Particularly abundant, very tame, and easily taken from projecting limbs of bushes. Four well marked varieties were observed, and both sexes were variable.

Anax junius, Drury.

Taken on the wing. It flies wildly over the open avenues near the casemates, and but rarely alights.

Aeschna Heros, Fab.

Seen flying in the same places as the last, but less frequently.

Aeschna clepsydra, Say.

Captured on the roof of a casemate. Only one specimen seen.

Agrion putridum, Hagen.

Two or three specimens seen on the rocks. All of these Dragon flies came from the adjacent mainland two or more miles distant; and as we are acquainted with a large number of others from this vicinity, it seems likely that most, if not all of them, live during a part of their nomadic life upon this artificial island.

The Development of Lingula and the Systematic Position of the Brachiopoda.

By W. K. Brooks.

It has been known for nearly twenty years that some of the hingeless Brachiopods pass through a free-swimming larval stage. Fritz Müller has figured and briefly described this stage of development of an unknown Brachiopod from the coast of Brazil, and Mr. Crady has given a very brief description, from memory, of the swimming larva of Lingula. These papers, which will be more fully referred to at the close of the present article, are of interest, since they establish the fact that these two forms do pass through a locomotive stage; but the papers are very incomplete, as neither of the observers traced in detail the transformation into the adult. They agree in describing the larva as furnished with a locomotive apparatus which consists of a crown of ciliated tentacles capable of more or less retraction and expansion; and in describing the animal as enclosed in a flattened orbicular bivalve shell, without a peduncle.

A more exact knowledge of the structure of the larva and of its transformation into the adult is greatly to be desired, and I was therefore much pleased to find the larva of Lingula in the vicinity of Fort Wool, during the past summer, in considerable abundance. I succeeded in tracing its development from a very early stage to the time when most of the adult characteristics have appeared, and my observations not only show that Mr. Crady's fragmentary account is correct in every particular, but also give us a very thorough acquaintance with the embryo. It will also be seen that there is a close general similarity between Müller's larva and the young Lingula, and at the same time considerable difference in unimportant characteristics.

GENERAL DESCRIPTION OF THE LARVA.

The free-swimming embryos of *Lingula pyramidata* (Stimpson) were met with in abundance at Fort Wool, from about the middle of July to the middle of August, and as the youngest stages were met with in the early part of this period, while only the older larvae were found at the end, it is probable that the breeding season is short. No adults were found until the end of July, and the reproductive organs did not then

present any indications of functional activity, and although a number of individuals were kept in an aquarium for several weeks no eggs were laid, and I was unable to obtain the early stages of development.

The larva, Plate 1, Figures 1 and 2, and Plate 2, Figure 3, is enclosed between two orbicular flattened valves, which are not articulated to each other, but are free around the entire circumference. The dark-colored, somewhat opaque, flask-shaped digestive organs occupy the centre of the cavity of the shell, and are in contact above and below with the integument which lines the valves. Around the digestive organs is a body-cavity bounded externally by the integument, which is continuous with the mouth above and below, and is bent downward at right angles to the valves to form the body walls. On the sides of, and behind, and in front of the body, there is a capacious mantle chamber which is open around the entire circumference. The mouth opens in the centre of a broad, flat, nearly circular disc or lophophore, around the margin of which are the ciliated tentacles. The plane of the lophophore is not at right angles to the long axis of the body, but inclined so as to be nearly parallel to it. The tips of the tentacles may be extended beyond the edges of the valves and thus form a swimming apparatus, somewhat like the velum of a mollusk,

by the aid of which the larva floats in the water or rises slowly to the surface. I have never seen the lophophore stretched out as in Müller's figure, however.

THE SHELL, AND THE CHANGES IN THE FORM OF THE LARVA.

The youngest stage which was studied is shown in Figure 1; it was captured with a hand net at the surface of the water, on the evening of July 22d. The figure is drawn to scale as seen with a magnifying power of 250 diameters. (Zeiss, Obj. D, Oc. 2.) The changes undergone by the larva during development are gradual, and do not involve any marked metamorphosis, and we may therefore refer the topography of the larva to that of the adult. In the figure, that valve of the shell which is uppermost, is to become the movable valve of the adult; that which Conchologists have agreed to call the dorsal valve, while the peduncle is to be attached to the opposite valve which is accordingly ventral. The nearly straight margin of the shell is that from which the peduncle is subsequently to project, and therefore indicates the posterior end of the body, while the opposite rounded margin is anterior. The right and left valves of the animal, are those which lie to the right and left respectively in this figure. The

valves are thin, brittle and transparent, and are very nearly alike in shape and size. At this stage they are somewhat wider than long, and the outline is pretty uniformly curved, except at the posterior end, which is nearly straight, and at this stage about as long as two-thirds of the antero-posterior axis of the shell. At the ends of this line are two tooth-like processes which project outwards and backward. The straight portion of the ventral valve is a little longer than that of the dorsal valve, the teeth of which *a*, *a*, are inside the teeth *b*, *b*, of the ventral valve. The surfaces of the valves are nearly flat, and the cavity between them very shallow. The thickness is so slight as compared with the width, that a floating larva, seen with a hand lens, seems to vanish when it rotates so as to present an edge view. The teeth of the dorsal valve are connected by a delicate line *c*, like the arc of a circle, of which the margin of the valve between the teeth is the chord, and with a versed sine equal at this stage to about one-third of the antero-posterior diameter of the embryo. As the straight posterior margin, the teeth and the semicircular line do not change their absolute size during the growth of the larva, and as the straight margin and teeth may be seen in the young Lingula after it has acquired most of the adult characteristics, these structures furnish us with a very convenient

standard, by reference to which changes in the size and shape of other parts may be readily described and properly estimated.

As the shell grows the additions take place at the sides and anterior edge, and the longitudinal axis therefore increases faster than the transverse, and the outline soon becomes circular, and then gradually elongates. At the stage shown in Figure 2, which is a ventral view, the shell is nearly circular, but a little longer than wide, while in the stage shown in Figure 3, (a dorsal view,) the longitudinal axis is considerably longer than the transverse. Since the line *aa* is of the same absolute size, at all stages of development, it will be seen that the embryo of Figure 3 is much larger and less highly magnified than that shown in Figure 2.

The body has also increased in size, and the semicircular line *c*, which in Figure 1, *c*, reached to the middle of the body, now reaches only to its posterior extremity.

As the larvae could not be made to thrive in confinement, the actual change from the free to the sedentary form was not observed, but it probably takes place soon after the stage shown in Figure 3.

The youngest sedentary Lingula which was found is shown in Figure 7, Plate 4, as seen from the ventral surface; and in Figure 8, Plate

5, as seen from the dorsal surface. The small vertical line at the right of Figure 7, gives the actual length of the now greatly elongated shell, which is more than twice as long as wide and pretty regularly elliptical in outline. The two valves are still about equal in size, as is shown in Figure 8, where the dorsal valve is rotated a little upon its centre, so that the axes of the two valves cross each other like the halves of a pair of scissors. At the posterior end of the shell, in Figures 7 and 8, there is an elliptical line *nu*, the edge of the *nucleus;* as this is only a little larger than the shell of Figure 3, and of about the same size, it probably shows the shape of the shell at the time when the larva settles at the bottom. It is about one-seventh longer than wide, and its anterior margin is the arc of a circle. The adult shell does not differ very much from that of Figures 7 and 8. (See the excellent figures by Morse. The Systematic Position of the Brachiopoda, by Prof. E. S. Morse, Proc. Boston Soc. Nat. Hist., vol. xv, 1873. Plate 1, Figures 2 and 3.) It is about twice as long as wide, and the anterior end is rectangular. I was not able to learn anything of the significance of the semicircular plate shown in Figures 1 and 3. It is found only in the dorsal valve, and is either a mark upon its inner surface or a plate between the body and the valve. According to Fritz

Müller, the Brachiopod larva studied by him possessed a similar structure, which in this case was a distinct movable plate capable of being rotated backward upon the posterior margin of the shell. He says, (Reichert u, Du Bois-Reymond's Archiv., 1860, p. 74,) "Mit ihrem Hinterrande dem ausgebuchteten Hinterrande der Bauchschale anliegend, gewahrt man zwischen den Schalen eine querovale Platte, 6.06 mm. lang, 0.11 mm. breit, mit dunklerem oft braunrothlich gefärbtem, ringförmigem Rande. Sie haftet an der Bauchschale, deren Bewegungen sie folgt, und steht mit der Rückenschale nur durch Muskeln in Verbindung." In his second paper, (Arch. f. Naturgeschichte, 1861, p. 54,) he says that after the animal settles to the bottom "die bis dahin zwischen den Schalen verborgene querovale Platte (der Stiel) tritt hervor, indem sie sich, wie es scheint, um dem ausgebuchteten Hinterrande der Bauchschale vollständig herumdreht und so ihr vorderer Rand zum hinteren wird." In an older embryo, p. 55, he found no traces of the plate. The embryo of Lingula is so small and thin that if this were a separate plate, it would be rather difficult to prove without seeing it move, or finding it bent outward. In the absence of such evidence, we seem warranted in concluding that it is a similar structure to the movable plate of Müller's larva, although, in Lingula at least, it is

in connection with the dorsal, not the ventral valve. If it is the same, Müller is certainly in error in his suggestion that it is the peduncle, for as I shall show, there is no connection between the two structures. It will be seen that if it is a plate bent inwards from the margin of the dorsal valve, it agrees closely in position and connections with the complicated structure which in the articulated Brachiopods, forms the hinge plate, crura, and loop which supports the arms.

Before I pass to the description of the internal organization of the larva, I wish to call attention briefly to the fact that the recent and fossil shells of the various species of Crania, Discina, Lingula, Lingubella, Obolus, and other hingeless Brachiopods, furnish a series of adult forms representing all the changes through which the outline of the shell of *Lingula pyramidata* passes during its development.

THE DIGESTIVE ORGANS.

In a dorsal view, at the earliest stage which was studied, Figure 1, the digestive organs are quite conspicuous since they form a somewhat opaque mass which fills the posterior half of the ventral portion of the otherwise quite transparent embryo. In a dorsal view at this stage, the digestive tract is very similar in shape to a long-necked round-

bottomed Florence flask; the œsophagus corresponding to the neck, while the stomach represents body of the flask.

The thick walled muscular œsophagus, Figures 1 and 4, *i*, is lined with cilia and runs forward from the stomach on the median line, nearly to its anterior end, where it bends sharply at right angles, towards the ventral surface. The mouth accordingly has a ventral aspect, and in a dorsal view, Figures 1, 3, 4 and 6, *o*, it is seen through the bend of the œsophagus, while in a ventral view, Figures 2 and 5, *o*, its surface is shown. It is widely open, and is ciliated like the œsophagus, and small food particles are continually drawn into it and whirled down the open œsophagus into the stomach, *k*, *l*. The latter is a large, permanently dilated ciliated thick-walled pouch, and is imperfectly divided into two chambers. The one nearest the mouth, Figures 1 and 2, *k*, is the largest, and its walls are filled with dark yellow, highly refractive oil-like globules. This cavity I shall speak of hereafter as the oral chamber. It usually contains a mass of partially digested food, which occupies the centre of the cavity; does not touch the walls, and is kept in constant slow rotary motion by the ciliary lining. Near the bottom of this chamber the walls are a little raised so as to form an elevated line; the lower border of what is to become the liver of the adult, which is divided at this stage into two

lobes, *n*, Figure 1, which are separated from each other upon the median line, of about half the dorsal surface of the oral chamber of the stomach. The posterior end of the stomach is formed by a second chamber, which is nearly spherical, with thick transparent ciliated walls, without oil globules, *l*, Figure 1. This chamber I shall call the intestinal, since it communicates with the intestine. It is only imperfectly separated from the oral chamber, but owing to the opacity of the walls of the latter, I was not able to make out the exact form of the opening between the two.

The intestine, *m*, Figure 2, (ventral view,) originates upon the ventral side of the posterior end of the intestinal chamber, and passes forwards, ventral to the stomach, to the anus, *n*, Figure 2, which is upon the right side of the body.

The intestine was present in the youngest larva which was carefully studied, and in Figure 1, its edge is shown at *m*, projecting beyond the margin of the stomach, but at a somewhat later stage, Figure 2, its cavity was not yet in communication with the cavity of the stomach, and there was no external opening. As Müller speaks of a stage in which it was wanting in his larva, it probably originates as a solid outgrowth from the posterior end of the stomach; meets and unites with the integument; becomes hollow; establishes a communication with the stomach, and finally opens externally by an anus.

In the ventral view, Figure 2, the distinction between the oral and intestinal chambers of the stomach is much less pronounced than upon the dorsal surface, and the oil globules come to an end irregularly below, without any sharp boundary. The digestive organs undergo very little change during development, and in the young sedentary Lingula, Figures 7 and 8, they have substantially the same form as in Figures 1 and 2. In Figure 4, they are shown in dorsal view, at about the same stage as Figure 2, but more highly magnified. In Figure 3, a somewhat older larva is shown in a dorsal view, and Figure 5 is a more magnified ventral, and Figure 6, a dorsal view of the body and viscera of the same larva. In the latter figures, it will be seen that the liver *h*, *h*, is now sharply folded off from the stomach below, and definitely limited along the lower margin, in both the ventral and dorsal aspects. In Figure 5, it will be seen that the intestinal chamber of the stomach, *l*, is now more definitely separated from the oral chamber *k*, which is now entirely covered by the liver.

The intestine *m*, is now quite conspicuous, and its cavity is filled with fæces, some of which were observed to pass out through the anal orifice, *n*.

By a comparison of Figures 1 and 2, it will be seen that the œsophagus opens into the stomach near its dorsal surface, and the dorsal surface of

the œsophagus is accordingly quite near the dorsal valve of the shell, while its ventral surface is quite removed from the ventral valve, and separated from it by a space which is part of the mantle cavity, and contains the ventral edge of the lophophore. This arrangement of parts is shown in the diagrammatic longitudinal section, Figure 16, Plate 6, where the dorsal valve is upon the right side.

THE BODY-CAVITY, OR PERIVISCERAL-CAVITY.

Surrounding the digestive organs is a body cavity, *g*, Figures 1, 2, 3, 4, 5, 6, 7 and 8, which is limited externally by a muscular integument, (*f*) or body-wall. This cavity is quite narrow in the younger larvae, and becomes more capacious as development progresses, but its size is very variable, owing to the contractility of the body-wall. In Figure 4, it is almost obliterated, and the integument is in contact with the surface of the digestive tract except around the bottom of the œsophagus, where the cavity *g*, is still visible. In another figure (2) of the same stage the body cavity is quite conspicuous, and in a younger embryo, (1) it was recognizable around the whole stomach. This difference is due in part, to the fact that Figure 4 was drawn from a larva which was somewhat compressed, but the body-wall was

often observed to expand and contract to an almost equal degree.

As shown in Figures 5 and 6, the inner surface of the integument is richly ciliated, and the body-cavity is filled with a corpusculated fluid which is kept in constant motion by the action of the cilia, and by the contractions of the integument. No cilia were visible upon the outer surface of the digestive tract, and they are probably restricted to the integument.

In the adult, this body-cavity is pretty completely filled by the muscles and reproductive organs, and its relations are consequently obscure, but in the larva shown in Figure 8, which has acquired most of the adult characteristics, its arrangement is substantially the same as in the larva, and the integument is contractile.

THE BLOOD.

Whenever a considerable quantity of the corpusculated fluid is massed together, it is seen to have a distinct, but faint, violet color, and in such accumulations many of the corpuscles were observed to have a singular dancing motion which did not seem to be due to the contraction of the body-wall, or to the action of its cilia.

The indications of an independent power of motion in the corpuscles themselves, were in some cases so marked, that I attributed them for some time to the presence of parasitic infusoria in the body-cavity, and I even thought that what I had regarded as blood corpuscles might be parasitic organisms. The appearance could be seen at all stages of growth whenever the corpuscles accumulated, and upon examining some of the fluid from an adult Lingula, I found it to contain two kinds of corpuscles, in about equal numbers, as shown in Figure 12, Plate 6. One kind are small, colorless, nearly spherical, and usually quite granular; their surfaces are frequently roughened or covered with projecting knobs. They exhibit slight changes of form, the knobs making their appearance upon the smooth surface of a corpuscle, and again gradually disappearing. Many of the smooth corpuscles of this kind have a cup-shaped depression upon one side.

The other sort of corpuscles are very peculiar; they are much larger, vary greatly in size and shape, but are usually more or less fusiform. In a thin stratum they appear colorless, but aggregations have a faint violet tinge. They consist of transparent protoplasm without granules, and with no visible nucleus. Running out from one or both of the pointed ends of many of the corpuscles are long delicate filaments of variable length;

frequently four or five times as long as the enlarged portion. These flagella were wanting in many of the corpuscles, and in one or two cases they were seen to gradually disappear, as if they had been retracted into the substance of the corpuscle. The blood, when removed from the body, was perfectly motionless; the dancing motion having stopped, and none of the flagella were seen in motion, and it is possible that the movements of the corpuscles in the body-cavity are entirely due to the action of the cilia of the integument. It certainly did not have that appearance, and, as I have said above, my attention was attracted by the movements before I found the flagella. I think, then, that there is no reason to doubt that the flagella are motile, and give to the corpuscles a proper motion.

Fusiform corpuscles in process of division into two were numerous, and several were shown in the figure. Morse (Systematic position of the Brachiopoda, p. 25,) has called attention to the presence of these two kinds of corpuscles in the perivisceral fluid of Lingula, but he attributes the color of the fluid to the round corpuscles.

THE MANTLE AND INTEGUMENT.

During the earlier stages of development the mantle is quite transparent, except around its circumference, where it forms a thickened granular opaque rim, concentric with and near the margin of the shell. (See Figures 1 and 2.) The rim is at first of uniform width, but at the stage shown in Figure 3, it is much wider at the anterior end and sides than posteriorly, and setae are now developed in it, pointing towards and protruding from the margin of the shell. These are at first sparsely scattered, but soon become more numerous, and at the stage shown in Figure 8, they are not of equal length; those near the posterior end of the shell being quite long; those in front of them much shorter; those about half way between the middle and the anterior end long, as well as those at the anterior end. They are movable and readily drop off, and in the adult they appear to be continually dropped and renewed, since the bottom of the vessel in which adults are kept alive, soon becomes covered with them.

At the stage shown in Figures 7 and 8, the anterior portion of the mantle is quite thick, and forms a broad opaque pad, upon which, in each valve, are four dark brown pigment spots; two smaller ones near the median line,

and two larger ones behind and outside of them.

The mantle which lines the valves outside the limits of the body is double, or made up of one layer lining the valve, and another facing the mantle chamber. These two layers are closely united, and during the earlier stages of development, they do not contain any vessels or diverticula from the body-cavity. Within the limits of the body proper these two layers separate and diverge, and while the outer layer still lines the shell the inner layer bends inward, and forms the integument of the sides of the body, and the dorsal and ventral aspects of the cavity thus formed are not alike. Dorsally, the whole surface of the digestive tract, from the posterior end of the stomach to the anterior end of the œsophagus, is separated from the lining of the shell only by the body-cavity, while on the ventral surface the œsophagus is invested by the integument, and the digestive organs are in contact with the lining of the ventral valve only as far forwards as the anterior margin of the stomach. If we start at about the point d^3 in Figure 2, and pass inward toward the median line, we shall have a double pallial membrane lining the ventral valve as far as the point *n*. Here the two layers separate, and from *n* to *f* the shell is lined only by the outer layer, while from *f* to the margin of the shell the

mantle is again double. At *n*, the inner layer bends down to form the body-wall of the right side, and upon reaching the dorsal valve, it again unites with the outer layer and bends outward to the edge of the shell.

Starting at the middle of the anterior margin of the ventral valve, at about the point where the letter *d* is placed in Figure 2, we have a double mantle running back as far as the letter *x*, where the inner layer bends inwards at right angles to form the anterior wall of the body; reaching the base of the œsophagus, it again bends forward to form its ventral wall which extends nearly to the mouth; then bends backward, and towards the ventral valve to form the lower or posterior face of the lophophore; at the ventral edge of the lophophore, it bends upon itself to form the upper surface, which extends to the mouth where the integument meets the lining of the digestive tract. These foldings of the integument will be more easily understood by the examination of the diagrammatic longitudinal section shown in Figure 16; the ventral valve being at the left side of the figure. From this description it will be seen that the open mantle chamber extends backwards on the ventral surface as far as the letter *x*, in Figure 2, and also runs forwards again between the lophophore and the œsophagus nearly as far as the mouth.

Starting at the point *d* on the dorsal surface in Figure 1, we have the integument running back only to a point a little beyond the letter *e*, and then bending down and forwards onto the lophophore, as shown on the right side of the diagram, Figure 16; so that the dorsal aspect of the mantle chamber is quite shallow. The portions of the mantle chamber at the sides of the body communicate posteriorly behind the body, and floating particles were seen to pass from one to the other without passing outside the shell; but as the mantle is here greatly thickened, the mantle chamber appears in surface view to be divided by a partition.

THE PALLIAL SINUSES.

During the earlier stages the two layers of the mantle are closely united outside the limits of the body, forming a solid mantle fold, without vessels or other visible cavities; but at about the stage shown in Figure 3, four diverticula from the body-cavity make their appearance, and penetrate between the two layers of the mantle, one on each side of the body in the mantle of both the dorsal and the ventral valve. They rapidly increase in size and form two long horn-like chambers on each surface of the body, Figures 5 and 6, *v*, which run forwards within the mantle,

nearly to the anterior margin of the valve. They communicate with the body-cavity by large ciliated funnel-shaped apertures, Figures 5 and 6, *w*, and they are richly ciliated internally, and the blood corpuscles are constantly driven into and drawn out of them by the irregular contractions of the body-wall. There is thus a very perfect circulation of the blood in these chambers; the muscular integument performing the function of a pulsating heart.

Soon a second diverticulum makes its appearance, running back from the posterior margin of the first, near the point where the latter bends down to open into the body-cavity. This second chamber, which is shown, but not lettered in Figures 7 and 8, extends back towards the posterior margin of the shell, and like the first is ciliated and filled with blood. The outer margins of these "pallial sinuses" now give rise to numerous small diverticula which lengthen and project downwards into the pallial cavity, as little papillae, or "ampullae," the well known respiratory organs of the adult Lingula. The fact that some of the earlier students of the anatomy of the Brachiopods figured and described from alcoholic specimens a heart and a system of blood vessels, has given rise to much confusion in regard to the blood circulation in the group; but the labors of Semper, (Z. Z., xiv, p. 424); MacDonald, (Trans.

Linn. Soc., xxiii, p. 373), and Morse, (Systematic position of the Brachiopoda, p. 24), and others have satisfactorily settled the question, and shown that there are no distinct blood vessels and no heart, and that the circulation is due in part to ciliary action. My observations are, so far, only corroborative of this now generally accepted view, but as these observers studied only the comparatively large and opaque adults, they overlooked the important part played by the integument in propelling the blood.

THE MUSCLES.

Almost every naturalist who has written upon the anatomy of the Brachiopoda, has proposed a new name for each muscle, and the confusion thence arising is much to be regretted. In order to escape the employment of a cumbersome synonomy, it seems most convenient to make use of arbitrary letters to designate the muscles instead of descriptive names, and, in order to facilitate comparison with the myology of the adult, I shall call the muscles of the adult Lingula, by the letters which mark them in Figures 23, 24 and 25, of the article "Brachiopoda," by Davidson, in the Encyclopædia Britanica, Ninth Edition.

In the youngest stage observed, only a single pair of muscles *p*, Figure 1, were present. They

are situated on each side of the œsophagus, close to its union with the stomach, and traverse the body cavity from one valve to the other. They are the muscles "*h*," of the article "Brachiopoda," and by their contraction bring the two valves together, compressing the body between them. The separation of the valves appears to be accomplished at this stage entirely by the muscular integument. When the muscles "*h*," are relaxed and the lateral walls of the body contracted, the width of the body is diminished and its thickness increased, and the valves thus pushed apart. These muscles were found at all stages, and are shown at *p*, in Figures 1, 2, 3, 4, 5, 6, 7 and 8. At a somewhat later stage, Figure 2, the integument at the posterior end of the body is much thickened, and soon a band of muscular fibres, *r*, make their appearance in it, upon the median line, and run directly from one valve to the other. At the stages shown in Figures 4 and 3, the fibres have increased in numbers, and form a well marked muscular bundle, *r*, which is shown in all the succeeding figures, and is the muscle "*g*."

When contracted at the same time with the muscles "*h*," this muscle serves to flatten the body still more, and this brings the two valves closer together; but when the muscles "*h*" are relaxed and the muscle "*g*" alone contracted, the posterior margins of the valves are brought

together and their anterior edges thrown apart, the body furnishing the fulcrum around which they turn.

At about the stage of development shown in Figure 3, three pairs of muscles make their appearance in the body-cavity at the sides of the stomach, two on the dorsal and one on the ventral side. They are shown at *u*, *u'* and *u''* in Figures 5 and 6. In Figure 5, the ventral ends of one pair are seen at *u* attached to the shell inside the limits of the body-cavity on each side of the posterior end of the hepatic chamber of the stomach. Dorsally they run forwards, and appear to unite with the dorsal ends of the muscles "*h*," as no independent ends of similar muscles were visible in a dorsal view. They are the muscles "*j*" of the adult.

In a dorsal view of the same larva, Figure 6, the dorsal ends of two pairs of muscles are seen at *u'* and *u''*. They are attached to the shell a little outside the limits of the body, and the integument bends out with them at *z*. One pair of them, *u'*, run forwards and downwards, and apparently unite with the ventral ends of the muscles "*h*," for no corresponding independent muscles could be seen in a ventral view. In Figure 7, the ventral end *p* of the muscle "*h*" is plainly seen to be divided into two by a longitudinal line, and a comparison with the Ency-

clopædia figures will show that the outer half is the ventral end of the muscle *u'* of Figure 6. This muscle apparently corresponds to the two muscles "*k*" and "*l*" of the adult, and it probably divides into two at a later stage. It would appear, then, from these observations, that the muscles "*j*," "*k*" and "*l*" of the adult Lingula are derived from the muscle "*h*," some of its fibres separating from it at the ventral end to form the muscle "*j*," but remaining for some time united to it dorsally; while another bundle separates from the dorsal end, but remains attached for some time ventrally, and gives rise to the muscles "*k*" and "*l*."

According to King and Davidson, these three pairs of muscles are adapted to move the valves forwards and backwards upon each other, but as my observations show that neither the larva nor the adult does slide its valves backwards and forwards to any marked degree, it seems more probable that they, together with the pair of muscles next to be described, cause the rotation of one valve upon the other, around the body as a centre.

In the dorsal view, Figure 6, a part of the muscles *u''* are shown, attached to the shell close to the muscles last described, and running backwards and inwards under the stomach. They are the muscles "*i*," which, in the adult, cross each

other under the digestive organs, and are the principal causes of the rotation of one valve upon another, which has been described by Semper and Morse, and which is represented in Figure 8.

We thus have, at the stage shown in Figure 3, and while the larva is yet a free swimming animal, something to represent all the muscles which have been described in the adult; and, in addition to them, I find upon the ventral surface a pair of muscles, Figure 5, *yy*, which have never been described. They run from the anterior margin of the stomach to the posterior end of the body, where they unite with the mantle, close to the ventral end of the muscle "*g*." They appear to be adapted to pull the œsophagus and lophophore back into the shell, and may therefore be spoken of as *retractor muscles.*

In the more advanced stages shown in Figure 7 and 8, the body-wall was too opaque to allow the muscles to be seen in a surface view, and the sections which I have made of the young Lingula at this stage will be described in another place. I may say, however, that these sections show that the view given above as to the adult homology of the muscles of the swimming larva is correct.

The muscles of the peduncle will be spoken of in connection with that organ.

Running along the dorsal surface of the stomach in Figure 6, is a thickened ridge 1, which appears to connect the stomach with the lining of the dorsal valve. It appears to be solid, and it certainly exhibited no pulsations or contractions, so long as the shell of the larva remained sufficiently transparent to allow it to be examined.

THE NERVOUS SYSTEM AND SENSE ORGANS.

During the later stages, Figures 7 and 8, the shell and body-wall were too opaque to permit of the minute study of underlying structures, and at the stage shown in Figures 1 and 2, the nervous system was very imperfectly developed, and I will therefore speak first of the stage in which it was most satisfactorily studied, that shown in Figures 3, 5 and 6. At this stage it consists of a commissural ring x', Figure 6, which encircles the œsophagus, at its union with the stomach, and carries one ventral ganglionic enlargement, Figure 5, x, and two lateral ganglia, Figure 6, x'', and two dorsal otocysts, Figure 6, x'''.

The ventral median ganglionic mass, shown at x, in Figures 2, 3, 5 and 7, is the largest and most conspicuous portion of the nervous system, as well as the first to make its appearance in the larva. It is situated upon the inner or posterior face of

the fold of integument which forms the anterior wall of the body, and which runs from the ventral valve to the base of the œsophagus, as shown in the diagram, Figure 16, *q*. It is formed by a thickening of the integument, and there is no line separating the nervous from the integumentary portion, and while the rest of the nervous system is separated from the body-wall, and lies upon the surface of the digestive tract, this, the first portion to make its appearance, is permanently united to the integument, and as we shall see that the rest of the nervous system grows out from it on each side, it is plain that after the analogy of most animals in which embryonic history has not been greatly modified by adaptation, the nervous system of Lingula is ectodermal in its origin.

At the earliest stage observed, this ganglion was present, and a little later that the stage shown in Figure 1, its ends are prolonged into two fibres, which are free from the integument, and bend around the œsophagus. At first they reach only about half way round the œsophagus, and end in the two lateral ganglia *x''*, Figures 4 and 6.

These are transparent, slightly granular, and without pigment, although Müller figures and describes in his larva, (Reichert u. Du Bois-Reymond's Archiv., 1860, Taf. 1, B. Fig. 1,) a pair of brown pigmented eye spots, which are identical in position with these ganglia of Lingula,

and are no doubt the same structures. At about the stage shown in Figure 2, the nerve fibres have lengthened as shown in the dorsal view, Figure 4, and now reach to the dorsal surface of the stomach upon which they lie. They now terminate in a pair of large dilatations, Figures 4 and 6, x''', each of which contains an elliptical cavity, within which are numerous vibrating otoliths. These organs were figured and described by Müller in 1860, and to him, therefore, belongs the credit of first discovering them. I am unable to agree with Morse in his view that the otocysts exhibit any annelidan characteristics; they are precisely such structures as are found in most of the Mollusca, and in numerous other animals of the most diverse forms, and are absolutely without morphological significance, in the present state of our knowledge, at least. At the stage of development shown in Figure 3, the otocysts are connected by a dorsal commissure, and the nerve-ring is thus a complete circle surrounding the œsophagus. In the young sedentary Lingula the shell is too opaque to allow the nervous system to be examined carefully, but in a ventral view, Figure 7, x, the ventral ganglion was visible, and in a dorsal view, Figure 8, x', the dorsal portion of the ring. It should be recollected that Figure 8 is much larger and less highly magnified than Figure 3, and if the otocysts had been present,

and no larger than those of the latter figure, they would not have been visible with any available magnifying power. There is no reason, therefore, to suppose that they disappear during development.

THE PEDUNCLE.

In the youngest larva which was studied, Figure 1, there is no trace of the peduncle, and the posterior end of the body is attached by a membrane formed by the thickening of the integument to the posterior margin of the mantle. At about the same time that the muscle *r*, Figure 2, makes its appearance, the peduncle *s* also appears, a little to the right of the posterior end of the body, and it is soon seen to be a hollow structure, surrounded by a double wall. When more highly magnified, Figure 9, Plate 6, the two layers which enter into its wall are quite distinct, 1 and 2, and the large central space is seen to be ciliated, and contains blood-corpuscles. These are driven into and out of the cavity of the peduncle by the motions of the body, and there is evidently a free communication between the body-cavity and the cavity of the peduncle. When seen from the dorsal surface, Figure 9, the outline of the peduncle is complete, and it is necessary to examine the ventral surface in order to study its connec-

tion with the body. Figure 10, Plate 6, is a ventral view of the posterior portion of the body and digestive organs of a larva of about the same age as that shown in Figure 2, and Figure 9 is a dorsal view of another larva of about the same age. The ciliated integument *f*, the body-cavity *g*, the intestinal chamber of the stomach *l*, the intestine *m*, and the muscle *r*, are lettered as in the preceding figures.

In Figure 10, it is seen that the inner layer, 2, of the peduncle no longer forms a complete tube, but flattens out as it approaches the posterior end of the body, and appears to become continuous with the muscle *r*, while the outer layer, 1, becomes continuous with the integument of the posterior end of the body. It will be observed that the ciliated epithelium which lines the body-cavity, is anterior to the muscle *r*, and that this muscle lies between the two layers of epithelium which form the outer and inner faces of the integument.

These facts seem to indicate that the peduncle is simply a diverticulum from the posterior end of the body, formed by a tubular outgrowth from the integument, with a cavity which is in communication with that of the body.

The ciliated epithelium of the inner surface of the peduncle is continuous with that of the body, its outer layer is continuous with the integument, and between this and the ciliated epithelium is

a circular layer of muscles continuous with the muscle *r*.

The peduncle now rapidly increases in length and soon bends abruptly upon itself, and passes behind the body so that its free end, *s'*, now lies upon the left side, as shown in Figures 11 and 3. Its free end now becomes somewhat enlarged, and as it continues to increase in length, it becomes sharply bent upon itself at short intervals, as shown in Figure 3. As long as the larva swims freely in the water it is coiled up within the shell, and although it is somewhat contractile, and changes its shape, it is never extended. The contraction of the circular muscles of its wall at somewhat regular intervals, give it a wrinkled appearance, which has been mistaken by Morse, (Systematic position of the Brachiopoda, p. 11,) for segmentation.

The wrinkles are, however, not permanent, and I have been unable to find, at any stage of development, any indication that the peduncle is made up of segments.

We cannot fail to mark the contrast between the appearance of the peduncle at a very early stage of development in the hinged Brachiopods, according to the observations of Lacaze-Duthiers, Morse and Kowalevsky, and its appearance at a very much later stage in the hingeless forms as observed by Müller, McCrady, and myself.

If, as I shall try to show, the form of development which we have in Lingula, is the unabridged record of the ontogeny of the group, and that of the hinged forms an accelerated form of development, it is plain that the Brachiopodan peduncle is a structure which was acquired after that stage of ontogenetic development which is represented by the free unpedunculated larva, and is accordingly of no morphological value, so far as the question of the systematic position of the Brachiopoda is concerned.

THE LOPHOPHORE AND TENTACLES.

During the earlier stages the lophophore is nearly flat, Figures 1 and 2, *q*, and is inclined to the long axis of the body in such a way that its dorsal margin is anterior, and its ventral margin posterior to the mouth, which is, itself, ventral to the long axis of the œsophagus. In the diagrammatic longitudinal section, Figure 16, Plate 6, the thickness of the larva has been, for convenience, greatly exaggerated, as compared with the length, but a comparison of Figures 1 and 2, will show that the position of the lophophore is as it is represented in the diagram.

The tentacles which are arranged around the margin of the lophophore, increase in number

with the age of the larva. In Figure 1, there are only five pairs, and in Figure 7, sixteen pairs.

Only one of the tentacles is upon the median line; that which is dorsal to the mouth, and which is indicated by the letter *d*. The new tentacles appear in pairs at the base of this odd one, and are shown at d^n, in Figures 1, 2 and 3. As new tentacles are added, the old ones are pushed away from the median dorsal one, and crowded down towards the ventral margin of the lophophore, and in Figures 1, 2, 3, and 7, the series of letters d, d^1, d^2, d^3, d^4, ... d^n, indicate the relative ages of the tentacles; the single dorsal one being the oldest, and the pair nearest the ventral surface, the oldest pair. As shown in Figure 2, d^1, these are widely divergent from each other, and the lophophore is thus bilaterally symmetrical or hippocrepian from the first, and as in the hippocrepian Polyzoa, the notch or concave surface of the horse-shoe is upon that side of the body where the anus and nerve ganglion are situated. At an early stage, Figure 1, the antero-posterior diameter of the lophophore is about equal to the transverse, but as the number of tentacles increases, the sides of the lophophore lengthen as in Figure 2, where there are seven tentacles on each side. As the tentacles become more numerous, those at the sides of the lophophore are pushed out of the

series, and bend towards the dorsal surface, and in Figure 3, (dorsal view,) where there are nine pairs, this dorsal flexure is seen in all from the fifth, d^5, to the eighth, d^8, and the outline of the lophophore is no longer the same in a dorsal and a ventral view. In Figure 7, where there are sixteen pairs of tentacles, and in Figure 8, where there are eighteen, not only the tentacles, but the lateral edges of the lophophore are bent towards the dorsal surface, as shown at *q*, Figure 8. As the number of tentacles continues to increase, the lateral edges *qq* continue to lengthen, and thus form the lateral coiled "arms" of the adult, while the dorsal margin also lengthens, bends towards the dorsal surface and forms the median coiled "arm." The tentacles become the cirrhi of the adult, and are substantially the same in structure in the larva and in the adult. In Figure 14, the tip of a tentacle, and in Figure 15, the bases of three from the young Lingula shown in Figure 8, are figured, and in Figure 13, a number of tentacles, much less magnified, from an adult. Like the tentacles of a polyzoan, they are covered with cilia, and can be moved in all directions, and they also resemble the polyzoan tentacles in having no power of contraction and extension like those of a Hydroid. In the larva, when they are at rest, their positions are constant, and are carefully drawn in Figures 1, 2 and 3,

which will give a better idea of their peculiar arrangement than a description. They are hollow, as shown in Figures 14 and 15, and the wall is made up of two distinct layers, of which the inner alone appears to be muscular. Owing to the varying contraction of the muscles, the tentacle exhibits the same irregularly segmented appearance as that noticed in the peduncle.

The cavity of the tentacle appears to be filled with a fluid, but this is perfectly transparent, and contains no corpuscles, and does not appear to be connected with the body-cavity. Near the bases of the tentacles the outer layer and the cilia pass over to the adjacent tentacles, while the muscular layer and cavity extend for some distance into the lophophore, as shown in Figure 15.

THE OBSERVATIONS OF PREVIOUS WRITERS.

The larva of the hingeless Brachiopods has been studied to some extent, and accounts published by Fritz Müller and by McCrady. The embryo described and figured by Fritz Müller, (Beschreibung einer Brachiopoden larva, von Fritz Müller, in Destero, Brazilien. Reichert u. Du Bois-Reymond's Arch., 1860, pp. 72–80, Taf. 1, B.

Figures 1–3,) bears a very close resemblance to that of Lingula, although it presents many interesting points of difference. The larvae were found floating in the water, and as they could not be raised in confinement they were not traced to the adult form, and we are ignorant of the group of Brachiopoda to which they belong, but as the author also collected at the same place the shells of Crania or of some allied form, (see note, by Max Schultze,) it is probable that they are the young of the same species. The animal is enclosed in a flat bivalve shell, nearly similar in outline to that shown in Figure 1, of the present paper, but unlike Lingula, the dorsal valve is much larger and more arched than the ventral, beyond the margin of which it projects around the entire circumference. As in Lingula, the shell is thin, flexible, horny and transparent. At the place of the hinge a small oval plate lies transversely between the valves. The central portion of the mantle is thin and transparent, and thus, as in Lingula, forms a central clear space, which is surrounded by a thickened, somewhat opaque rim.

In the larval Lingula at about the same stage of development, this rim is not furnished with setae, but in Müller's larva there are numerous setae, of two kinds. The smaller ones are numerous and hair-like, and appear to correspond to

those which are developed in Lingula at a later stage. They project from the marginal rim of the dorsal valve, and bend down and hook on to the edge of the smaller ventral valve. The second kind of setae are very much larger, and are only ten in number, five on each side, and the surface is serrated in the largest pair.

Occupying, as in Lingula, the posterior half of the clear area is the body proper, rounded anteriorly, and attached by its entire upper and lower surfaces to the shell.

The long, muscular œsophagus leads into an opaque flask-shaped stomach, which is covered with hepatic cells, and seems to correspond to only the oral chamber of the stomach of Lingula. In the larva which is figured, there were no traces of an intestine, but at a later stage of development this was seen to run forwards from the posterior end of the stomach, to open by an anus on the right side of the body as in Lingula. The anterior end of the œsophagus has a ventral flexure, and the mouth is in the centre of the lophophore as in Lingula, but unlike Lingula, it is placed upon an elevation or mouth papilla.

The anterior half of the clear area of the shell is almost entirely occupied by the four pairs of arms, which are arranged around the edges of the lophophore which, as in Lingula, is placed obliquely to the long axis of the body, with its

anterior margin dorsal, and its posterior margin ventral to the mouth. The tentacles appeared to be hollow and were covered with cilia, and arranged in pairs on each side of a median dorsal tentacle, which is much shorter than the others, terminates in an enlarged brownly pigmented knob, and gradually disappears as development goes on. In Lingula, this tentacle is like the others, and is persistent.

Near the anterior end of the body, on each side of the stomach, are two dark brown oval eye spots; the long axis of the oval running obliquely outwards and backwards. No such eye spots were to be seen in the Lingula larva, but the lateral ganglia shown in Figure 6, *x''*, are in about the same position, and may be the structures which are supplied with pigment in Müller's larva.

The otocysts are figured and described substantially as they occur in Lingula, although Müller failed to trace the nervous system.

The larva is able to protrude the lophophore and tentacles from the shell, and in this position, as figured by Müller, it has a very striking resemblance to a Polyzöon. He says that it is also able to move along the bottom; sliding the valves of the shell over each other, and thus progressing by the aid of the large projecting setae.

He figures only one stage of development, and his account of the structure of the larva at this stage is fragmentary and incomplete, but it is enough to show that there is an essential similarity between it and Lingula.

He concludes the paper as follows, (p. 79:)

"Die Bedeutung unserer Larve für die systematische Stellung der Brachiopoden näher zu erörtern, muss ich mich enthalten, da ich die neueren Forschungen über Bryozoen nur durch Jahresberichte kenne, und ich selbst nur wenige Formen derselben ziemlich oberflächlich untersucht habe. Dem Eindruck des ersten Anblichs folgend, würde gewiss Jeder, der unser Thier lebend zwischen lebenden Muschellarven und Cellularien gesehen, ihm ohne Bedenken seine Stelle zur Seite des letzteren anweisen. Was dabei zunächst als ähnlich im Auge fällt, die kreisförmig gestalteten Tentakel, steht in auffallendem Gegensatz zu der Armbildung der erwachsenen Brachiopoden. Aber ob überhaupt unser Thier als Larve einer der bekannten Brachiopodenformen angehört, und nicht vielmehr pem noch unbekannten Repräsentanten einer neuen Gruppe mit kreisförmig gestalteten Armen, die dann in ähnlicher Weise den Meeresbryozoen mit Tentakelkranz entsprechen würde, wie die gewöhnlichen Brachiopoden den zweiarmigen Bryozoen des süssen Wassers?"

Our knowledge of the development of Lingula, shows that the resemblance which is suggested between the larva and a Polyzöon is fully born out by a more careful study of the organization of the larva. As regards the suggestion that Müller's larva may be the young of an unknown form of Brachiopod with the cirrhi arranged in a circle round the mouth, our observations have shown that the facts do not warrant any such conjecture. In both Lingula and Müller's larva, the lophophore is bilaterally symmetrical with reference to only one axis, the antero-posterior, and the

tentacles are arranged symmetrically in pairs, and there is an approach to the hippocrepian type from the first.

It is, of course, possible, although not at all probable, that it is the larva of an undescribed species; but there is not the least reason for supposing that this species is essentially different from Lingula.

During the two years following, Müller repeated his observations upon the larva, which was found during the late summer months. In 1861, he published a second paper, which contains an account of the habits of the larva, as well as a few new observations regarding its structure, but no new figures. (Arch. f. Naturgeschichte, 27, 1861, pp. 53–56.)

This paper was translated in full in the Ann. & Mag. Nat. Hist., 3d Series, vol. viii, p. 505, and for convenience I make the following extracts from the translation:

"When the little animals are placed in a good sized vessel of pure sea water, they slowly ascend; the slightly gaping shells stand perpendicularly, the hinge margin downward; close to the anterior margin the right arms spread out horizontally, like rays, with their lips slightly bent downwards, and the roundish knob situated between the uppermost pair projects beyond the plain of the arms. In this posture they move slowly about near the surface. When strongly shaken, or sometimes without any perceptible reason, they retract the arms and close the shells, when they slowly turn over and sink to the bottom, with the free margin downwards. If the arms be again protruded, the hinge margin also again turns downwards. The duration of this state never exceeds five or six days, and in general, the larvae adhere to the bottom or sides of the vessel in a still shorter time. When they adhere to the sides, the mouth

was always directed downwards; the ventral shell was strongly drawn forward until its anterior margin reached or passed that of the dorsal shell. . . . For a day or more, the animal remains contracted and quiet; then the shells being slightly opened, the arms are half extended, and strike inwards, one or more at a time, just as in the marine Bryozoa. The principal change in the soft parts consisted in the retrogression of the organs of sense. The eyes had become broken up into groups of about ten black points; the previously spherical auditory vesicles were shrunken into longish sacs, closely surrounding the otoliths. In somewhat older animals there was no trace of the organs of sense, although they had not lost their sensibility to light. . . . ."

He notices the gradual disappearance of the larger setae, and the formation of an intestine and anus upon the right side of the body, but he does not mention any change in the shape of the lophophore, or in the number of tentacles, or in the general form and organization of the body.

In the American Journal, 1860, p. 151, there is a short description by McCrady, of an embryo, which was correctly regarded by the author as the young of Lingula. He says:

"I have within a few days discovered an embryo which has at once so many affinities with the Bryozoa and the Brachiopoda, that I believe it to be an embryo Brachiopod, and very probably the young of Lingula pyramidata. It is an equilateral thin hyaline, straight bivalve shell, elliptical in outline, and with the valves very flat. Through this perfectly transparent shell is visible a lining membrane, or rather the borders of such a membrane, which is the mantle. Within this, and near the hinge, is a large flask-shaped body containing a digestive cavity, surrounded by a dark mass. This cavity extends into the neck of the bottle-shaped cavity,—the œsophagus—and terminates towards the gap of the shell, in a mouth. From the opposite or basal end of the digestive cavity goes off a pretty long intestine, which turns first to the left, makes several convolutions, and terminates in an anus between the valves of the shell."

It will be seen from this description that McCrady mistakes the peduncle for the intestine.

"The mouth lies on a somewhat triangular prolongation of the body-wall, which rests with its apex towards the gap of the shell, in the dorsal valve. The borders, right and left of the homologue of the arms, are fringed, each *with* about six cirrhi, the hindermost being the longest. The animal thus constituted, when quiet, withdraws its whole body, cirrhi and all, within the bivalve shell, which is tightly closed; but when in motion the shell is distinctly opened, and the gap of the valves is plainly visible, even to the naked eye. Through this aperture are thrust out the cirrhi, about twelve in number, which then arrange themselves in a circular funnel-like manner, precisely as in a Bryozoa polyp and by a plainly allied, and with its cirrhi or tentacles thus extended, the animal swims through the water with considerable rapidity. The cirrhi of the embryo, I take to be the homologue of the cirrhi of Brachiopoda and of Cristatella, and of Bryozoa generally. The rest of the structure, especially of the anus on the right, and the shape of the shell point, I think to Lingula embryo with cirrhi extended, about a line in length. There is no trace of a peduncle. It appears to me that this must set at rest all difficulty about the approximation of the Brachiopoda and Bryozoa, as proposed by Agassiz, and others."

McCrady promised a more extended illustrated paper upon the subject, but owing to the destruction of his notes and drawings during the war, this never appeared.

In Morse's paper upon the Embryology of Terebratulina, p. 261, a second brief memorandum, drawn up by McCrady, is printed.

Although his account is too brief to give any very exact idea of the larva, it is clear that almost every statement made by McCrady, agrees with the observations detailed in the present paper, and to him belongs the credit of first describing the locomotive Polyzöon-like larva of Lingula.

THE BEARING OF THE DEVELOPMENT OF LINGULA UPON THE SYSTEMATIC POSITION OF THE BRACHIOPODA.

A comparison of the more recent writings of a few of the standard authors upon general zoölogy, will show that the greatest diversity of opinion still exists, regarding the affinities and systematic position of the Brachiopoda. As long as the attention of the investigator was confined to the study of shells, there seemed to be no difficulty in connecting the Brachiopoda with the Lamellibranchs through such forms as Anomia. Although the slightest anatomical knowledge is sufficient to show that the resemblance between these forms is entirely superficial, and absolutely without scientific value, and although embryological investigations give the most complete confirmation to the conclusions founded upon anatomical research, this old view, first propounded by Linaeus, is still adhered to by some conchologists. (See, for instance, Woodward's Manual of the Mollusca, ed. 1868, p. 5.)

Tracing the history of the subject, we find this view replaced by another which is not open to the charge of superficiality, since it is based upon

a thorough knowledge of adult structure, and is shown to be worthless only when tested by the facts of embryology. According to this view the Brachiopoda and Polyzoa are connected with the Lamellibranchs through the Tunicates. The branchial sac of a Tunicate corresponds to the permanently retracted tentacular crown of the Polyzöon, and this again is homologous with the gills of a Lamellibranch. The recent great additions to our knowledge of the embryology of the Tunicata and Mollusca, and to our knowledge of the Lamellibranchiata gill, show with absolute conclusiveness that we here have nothing but an adult resemblance, reached in the two forms in entirely different ways, and without morphological significance.

Whatever view of the Vertebrate affinity of the Tunicata we may incline to, we must recognize the fact that the branchial sac is, morphologically, part of the digestive tract, and is in no sense whatever comparable with a lophophore or with a tentacular gill.

Moreover, we should expect, according to all analogy, to find the affinity to other groups most clearly shown by low or embryonic forms, but Appendicularia presents none of the characteristics upon which this comparison is based, and does not in the least resemble either the Lamellibranchs, Polyzoa or Brachiopods. This view is,

however, still maintained by many authors;[1] as an example, I may refer to Rolleston's Forms of Animal Life, ed. 1870, Introduction, pp. xxviii and lxxxvii, and Plate XI.

While most of the more recent writers recognize a pretty close relation between the Polyzoa and Brachiopoda, some associate them with the Mollusca, others regard them as a related group, (Molluscoida,) and others associate them with the Vermes. Huxley (Anatomy of Invertebrated Animals, p. 468,) says:

"The acceptance of the view originally propounded by Steenstrup, and so ably urged by Morse, respecting the affinities of the Brachiopods with the Worms, does not, to my mind, weaken the opinion I have always held as to their affinities with the Polyzoa, on the one hand, and with the higher Mollusca, on the other."

On page 453, he says:

"The higher Mollusks, in fact, form the final term of a series of their own, which commences in the Polyzoa, with animals which have many resemblances to the Rotifera."

Claus takes a somewhat similar view, and places the Brachiopoda and Polyzoa together between the Annelids and Mollusca. He says, (Grundzüge der Zoologie, 1876, p. 821:)

"Die Brachiopoden hat man oft als nahe Verwandte der Lamellibranchiaten betrachtet, die neueren Untersuchungen insbesondere über

1 In a paper read Feb. 2, 1876, before the Boston Soc. Nat. Hist. on the Affinity of the Molluscoida, I inadvertently (page 5,) appeared to refer to Lankester, as one of the adherents to this view. It is hardly necessary to point out that this author was, on the contrary, one of the first to accept the view that the Tunicates are in no way related to the Mollusca or Molluscoida.

die Entwickelung haben jedoch gezeigt, dass unsere Thiere zu den Bryozoen und Anneliden in näherer Beziehung stehen. Vorläufig mögen sie als Anhang den Mollusken angereiht werden, denen sie unter Voraussetzung einiger wesentlicher Abänderungen und Vereinfachungen des Baues immerhin noch untergeordnet werden könnten. Jedenfalls würde die Bezeichnung Molluskoideen die nächste Berechtigung für die Brachiopoden haben. Dem gegenwärtigen Stande unserer Kenntniss würde es freilich am besten entsprechen, für Bryozoen und Brachiopoden einen besondern Typus als Molluskoideen aufzustellen, und denselben zwischen Würmer und Mollusken einzuschieben."

Gegenbauer (Grundriss der Verg. Anat., 1878, pp. 134 and 325,) separates the Polyzoa from the Brachiopoda, and places the former group among the Vermes, while of the latter he makes a primary group which, however, he places near the Annelids. In reference to the position of the Brachiopoda, he says:

" Früher meist den Mollusken beigezählt, mit denen sie wenig mehr als den Besitz einer vom Molluskengehäuse noch dazu ganz differenten Schale gemein haben, bilden die Brachiopoden eine kleine und eng abgegrenzte Abtheilung, die ihren Ursprung zum Stamme der Würmer zurückverfolgen lässt. Hier sind es die Chätopoden, also schon höher differenzierte Formen, bei denen sich manche Anschlüsse erkennen lassen, aber nur manche, denn gerade in den wichtigsten Organsystemen ergeben sich so bedeutende Eigenthümlichkeiten, dass es gewagt wäre, auf jene Beziehungen eine bestimmte phylogenetische Behauptung zu gründen. Jedenfalls ist der gesammte Organismus der Brachiopoden im Vergleiche mit Chätopoden und Anneliden total umgestaltet, und lässt nur noch in einzelnen Rudimenten seine verwandtschaftlichen Beziehungen wahrnehmen."

According to Lankester, the Brachiopoda and Polyzoa are closely related to each other, and are to be associated with the Mollusca, but his conception of the precise nature of this relationship is different from that of any of the other authors quoted. He does not, like Huxley, regard the

group Mollusca as a single series, with the Polyzoa at the bottom and the higher forms at the top, nor does he accept the division of the group into Mollusca and Molluscoida, but divides it into two *branches*, the Eucephala and the Lipocephala, and in the second branch he places the Polyzoa, Brachiopoda and Lamellibranchia. (Quart. Jour. Mic. Sc., Oct., 1877, p. 448.) Finally, we have the extreme view of Morse, that the Brachiopods are not merely related to the Vermes, but are actually ancient cephalized Chaetopod Annelids. In his paper upon the "Systematic Position of the Brachiopoda," (Proc. Boston Soc. Nat. Hist., XV, 1873,) he summarizes his views as follows, (p. 57:)

"In the Brachiopods, while in every feature of their internal structure betraying their annelidan affinities, and while the errantian forms with their long vermiform and annulated peduncle, their locomotion by means of setae, and their power of fabricating a sand tube, unite them clearly with the fixed and highly cephalized Chaetopods: yet in those groups that are attached, a remarkable concentration is seen, and many features are presented which have heretofore obscured the affinities of the group.

"To sum up the whole then. Ancient Chaetopod worms culminated in two parallel lines, on the one hand, in the Brachiopods, and on the other, in the fixed and highly cephalized Chaetopods. The divergence of the Brachiopods having been attained in more ancient times, a few degraded features are yet retained, whose relationships we find in the lower Vermes; while from their later divergence the fixed and cephalized Annelids are more closely allied to present free Chaetopods. And so we must regard the Brachiopods as *ancient cephalized Chaetopods*, while Serpula, Amphitrite, Sabella, Protula and others may be regarded as *modern* (later) *cephalized Chaetopods.*"

It is rather difficult to decide what Morse's views are as to the relation of the Brachiopods to the Polyzoa. In the paper entitled "Early

Stages of Terebratulina," (1869,) he recognizes such a relationship, p. 36, and calls attention to many points of close resemblance between the embryo of Terebratulina and an adult Polyzöon.

In his second paper, on the "Systematic Position of the Brachiopoda," p. 47, he says:

"Naturalists are sufficiently well acquainted with the relations repeatedly pointed out, as existing between the Brachiopoda and the Polyzoa, and there is no necessity of again repeating them."

In his latest paper upon the subject, "The Embryology of Terebratulina," (1873,) he seems to be less inclined to accept this view, and on page 260, says:

"As to the relations of the Brachiopods with the Polyzoa, some features of similarity are seen between the embryo Brachiopod and the free embryo of Pedicellina, though the development of parts within a coenœcium and the formation of statoblasts are features quite unlike the Brachiopoda. A roundabout relation might possibly be insisted upon through the Rotifera, in their winter ova."

Packard, in his "Life Histories," 1876, gives a still different opinion. He says, p. 149:

"It will be seen that neither in the Polyzoa nor Brachiopods are there any true molluscan characters, nothing homologous with the foot, the shell-gland or odontophore. The Brachiopods should in our opinion be, perhaps, united with the Polyzoa and form a group lower but sub-parallel with the Annelides. The Brachiopods, from the facts afforded by Morse and others, have neither such a nervous system or respiratory or circulatory organs, or an annulated body, as would warrant their union with the Chaetopods. Morse has fully proved that they are a synthetic type, combining the features of different groups of worms, and this fact apparently forbids their being regarded as a group of Chaetopods.

"Looking at the subject from an evolutional point of view, we should be inclined to regard the Brachiopods and Polyzoa as derived from common low vermian ancestors, while the Chaetopod worms probably sprang independantly from a higher ancestry."

These various selections are enough to show the wide divergence of views among modern writers upon the affinities of the Brachiopoda, and it is not necessary to extend the list, but no two authorities will be found to take precisely the same view, and our citations of divergent opinions might be continued almost indefinitely. This difficulty in determining the true position of the group, ceases to be surprising when we recollect that the Brachiopods have been in existence through almost the whole period during which we have any evidence of the existence of life, and that, of the numerous and varied forms which have existed in the greatest diversity during the past, only a few isolated forms are now available for study.

The difference of opinion will be found upon comparison, to be mainly upon three points: 1st. Are the Polyzoa and Brachiopoda so closely related as to form a natural *phylum?* 2d. Assuming that they are, are their affinities with the Vermes, or with the Mollusca? 3d. Assuming their relationship to the Mollusca, in what does it consist, and with what Mollusca are they to be classed? It is now an accepted law of morphology, that such questions are to be decided mainly by the study of embryology. That classification based upon adult structure is purely ideal, and may or may not express phylogenetic

relationship, and that "the study of the development of individual animals, is alone competent to decide whether this ideal unity has a foundation in observed fact." (Huxley, Anat. of Invert. Animals, p. 681.)

It would seem that our embryological knowledge ought now to be sufficiently comprehensive to enable us to give demonstrable solutions to these questions, for imperfect as our knowledge still is, we know something of the embryology of nearly all those families of Brachiopods which are now represented by living species, and there is, perhaps, no equally important group of animals regarding whose embryology our knowledge is more extensive, as compared with the number of existing representatives.

From the observations of Lacaze-Duthiers, (Ann. d. Sc. Nat., xv, 1869, p. 259;) Morse, (Embryology of Terebratulina,) and Kowalevsky, (Obs. upon the Development of the Brachiopoda, 1874,)[1] we have a pretty complete history of the development of a number of genera of the hinged Brachiopoda or Testicardines. Lacaze-Duthiers and Kowalevsky having studied the embryology of Thecidium; Morse and Kowalevsky, Terebratulina, and Kowalevsky, Terebratulina and Ar-

1 My acquaintance with the contents of the Russian paper, by Kowalevsky, which I have not seen, is through the very short abstract given by Claus, in his Zoologie.

giope. According to these observers, the egg of a hinged Brachiopod gives rise after segmentation and the formation of a primitive digestive cavity, to a ciliated elongated embryo, which soon becomes divided by constrictions into three segments. (See Figures 17 and 19, after Lacaze-Duthiers.) The digestive tract, 6, is a pouch which extends about as far backwards as the middle of the second segment, which we may call the body segment, 4. The anterior segment (3, Figures 17 and 19,) develops a circlet of long cilia, which, in some of the genera, at least, is an organ of locomotion.

Soon, in Thecidium and Terebratulina at least, the trochic segment divides into two, an anterior smaller one, Figures 17 and 19, 1, which is little more than a prominence upon the anterior face of the next segment, and which carries the mouth opening and also in Thecidium four pigmented eye spots. This segment we may call the oral. The circlet of cilia is now carried upon the second, much larger segment, which may therefore be termed the trochic segment, 3. Posterior to the body segment is a fourth small segment, 5, which does not contain any part of the digestive cavity. At a later stage of development, the embryo attaches itself by the posterior end of this segment, which then becomes converted into the peduncle; it may therefore be called the peduncular seg-

ment. The dorsal and ventral surfaces of the body segment now give rise to two folds, which become the two halves of the mantle; they gradually extend forwards and cover up the oral and trochic segments, and also extend backwards so as to cover the posterior portion of the body segment and part of the peduncular segment. The embryo attaches itself by its peduncular segment; the two mantle folds become covered by the two valves of the horny shell, and setae make their appearance around their edges; the anterior segments give rise to the brachial organs, and the segmented larva is thus converted directly into the attached Brachiopod.

In the hingeless Brachiopods, which are the least specialized and oldest forms, the process of development is much more complicated, and before the adult form is reached, the animal passes through a free-swimming stage, during which it attains to considerable specialization of structure, and becomes quite highly organized at a time when it lacks many of the most important characteristics of an adult Brachiopod.

The larva at this stage has no setae, no peduncle, and no indication of transverse segmentation. It is enclosed within a bivalve flattened shell, within which the digestive organs are loosely suspended in a body-cavity. The large stomach consists of two chambers, and from the posterior one the

intestine runs forwards or towards the mouth, to open ventrally, but to the right of the median line. The mouth opens in the centre of a somewhat horse-shoe shaped lophophore, which is capable of more or less extension or protension towards or beyond the anterior margin of the shell, and which is surrounded by a circlet of ciliated movable, non-retractile tentacles; the ends of the horse-shoe point towards the ventral surface, and the nerve-ganglion which first appears is between the mouth and the anus, which is outside the circle of tentacles. The body-cavity contains a corpusculated fluid which is kept in motion partly by ciliary action and in part by the motions of the body. The transformation of this larva into the adult is gradual and without any marked metamorphosis, and the larval stage is confined to the hingeless Brachiopods.

If, now, we compare these embryonic stages of the Brachiopoda with the various embryos and adults of the animal kingdom in order to find the forms to which they bear the greatest resemblance, we notice, first, the resemblance pointed out by Morse, (Systematic Position of the Brachiopoda, p. 43,) between the ciliated segmented embryo and the embryos of the many forms of invertebrate life which have been associated together as Vermes, but if we make a more detailed comparison, I think we must conclude that the par-

ticular form of ciliated embryo, which that of the Brachiopods is most like, is that of the marine Polyzoa.

From the study of the embryology of a large number of marine Polyzoa, Loxosoma, Pedicellina, Phalangella, Alcyonidium, Lepralia, Porella, Disuscopora, Mollia, Bicellaria, Scrupocellaria, Canda, Bugula, Vesicularia, Serialaria, Illustrella, Membranipora, and Eucratea, Barrois shows (Mémoire sur l'Embryologie des Bryozoaires,) that the various forms of polyzoan embryos, which appear at first sight to be widely dissimilar and independent of each other, can be shown to be modifications of one simple form, which form is, however, not represented by any existing embryo, and is purely ideal. This architype is represented in Figure 7, Plate XVI, of his paper, and the figure is copied in outline as Figure 18, Plate 6, of the present paper. It is what Lankester (Notes on Embryology and Classification, Quart. Mic. Jour., Oct., 1877,) calls a "Telostomiate Architrochic" embryo, which, according to this author, is the hypothetical type of which the ciliated embryos of most of the invertebrates are modifications. It consists of a nearly cylindrical body, 4, 5, with a mouth, 2, at one end, which is surrounded by a circular band of cilia, 3. The mouth opens into a digestive cavity, 6, which is separated by a body-cavity from the body-wall.

Most of the polyzoan embryos, figured by Barrois, as so highly specialized, that the resemblance to the hypothetical architype is not very apparent without careful comparison; but in others, the specialization is less marked, and the resemblance is much more obvious; and in Loxosoma, which is, in many respects, the least specialized of the Polyzoa, we have, according to the observations of Kowalevsky, (Mem. Acad., St. Petersburg, 1866;) Barrois, (loc. cit.) and Vogt, (Arch. Zoölogie Experimantale, V, 1876, trans. by Hincks, Quart. Mic. Jour., Oct., 1877,) an embryo which is readily seen to be a pretty direct modification of the ideal type. In Figure 20, Plate 6, I have copied in outline one of Barrois' figures of the embryo of Loxosoma, (Plate XVI, Figure 8,) for comparison with Figure 18. The general resemblance is very close, but the embryo is much more specialized than the type. The mouth, Figure 2, is situated in the centre of an eminence or oral segment, 1, the ventral margin of which is produced into a singular tongue-like structure which is covered with long hairs, and is probably a sensory organ. The architroch is carried upon a distinct segment, 3, which is sharply separated from those before and behind it. The posterior portion of the body is divided into a body segment, 4, in which the digestive cavity is suspended, and which carries a singular sen-

sory organ upon its ventral surface, and a tail segment, 5.

If, now, we compare this architrochic embryo of Loxosoma with the embryo of Thecidium, as figured by Lacaze-Duthiers, we shall find that there is not merely a general similarity, such as Morse has pointed out between the embryo of Terebratulina and those of the Annelids and Rotifera, but a very close and minute resemblance which extends even to details. In fact, almost the only differences between the embryo of Loxosoma and that of Thecidium are those which relate to the organs of special sense. In Figures 17 and 19, Plate 6, I have copied in outline Figures 9 and 10, Plate 5, of Lacaze-Duthiers' paper, and in Figure 21 another (Plate I, Figure 14,) of Barrois' figures of the Loxosoma embryo. In each we have a bilaterally symmetrical embryo which is divided into four segments.

The most anterior segment, 1, is small in both and carries the mouth and special sense organs. The second or trochic segment, 2, is much larger, and its margin is set with long locomotor cilia. The digestive organs, 6, in each are loosely suspended in the body-cavity and reach about as far backward as the middle of the third or body segment, 4, and the fourth segment, 5, is much smaller than the third, and substantially alike in both. In both the dorsal surface is convex

and longer than the nearly straight ventral surface, and a comparison of Morse's Figure 87, Plate IX, (Embryology of Terebratulina,) with Barrois' Figures 17, 18 and 20, Plate I, will show that the side view of the Brachiopod embryo is very similar to that of the Loxosoma embryo. The similarity of the embryo of Loxosoma to the architype and the very unspecialized character of the adult, are very strong grounds for regarding its embryo as a very slightly, if at all "falsified" ancestral form, the "stock" from which the Polyzoa are descended, and it seems clear that the resemblance between this and the segmented embryo of the Brachiopods is much more perfect and detailed than the resemblances shown by Morse to exist, in a very general way, between the Brachiopod embryo and the embryos of Annelids, Gephyreans and Rotifera.

So far as this stage of development is concerned, then, I think we are now in a position to affirm and prove that the Brachiopod is more like the unspecialized polyzoan embryo, than it is like any other known organism, embryonic or adult.

Passing now to the free larva of the hingeless Brachiopods, we cannot fail to notice the great resemblance which it bears to the adult Polyzoa; especially to the incrusting forms and to the hippocrepian fresh water forms. Although Morse (Systematic Position of the Brachiopoda, p. 44,)

says of Müller's paper: "What could be more annelidan than the description of this larva?" Müller himself does not speak of any marked resemblance to an Annelid, and notices only the similarity to a Polyzöon, and McCrady notices the same resemblance. Our account of the organization of the Lingula larva shows that it is not only like a Polyzöon, but that it actually is one; as much so as the hydra stage of an Hydro-Medusa is a Hydra, or the tailed larva of Botryllus is an Appendicularia, and more so than a Tadpole is an Urodellan Batrachian.

If it were not a larva, but an adult, it would unquestionably be regarded as a solitary, swimming Polyzöon, with a highly specialized nervous system and sense organs. It resembles the incrusting Polyzoa in the possession of a bivalve, movable shell, and it resembles the fresh water Polyzoa in the form of its lophophore, and it differs from all the Polyzoa in being solitary, and in the presence of peculiar muscles, and in the perfection of its nervous system, and it cannot therefore be placed in any of the existing families of Polyzoa, but if it were an adult, it would not demand a new class for its reception, for it differs from ordinary Polyzoa much less than Rhabdopleura does.

The study of the summary given on pages 87 and 88, and of the section shown in Figure 16, Plate 6, will show that the resemblance to a

Polyzöon is both general and minute, and it does not seem necessary to point out the points of agreement.

Now what interpretation are we to give to these polyzoan resemblances? Morse has shown that the adult Brachiopod resembles the Annelids in many particulars, such as the presence of segmental organs which connect the body-cavity with the exterior, the possession of chitinous setae, and of a vascular system which is distinct from the perivisceral circulation, and which is filled with the pseud-haemal fluid distinct from the corpusculated nutritive fluid which fills the body-cavity, but we now know that these annelidan resemblances are reached, at least in the hingeless forms, by the specialization of a polyzoan larva, which is annelidan in no sense whatever.

The annelidan resemblances of the adult Brachiopod are unquestionable, and so also are the polyzoan resemblances of the larva, and we may suggest two methods of interpreting the facts. We may regard the development of the hinged Brachiopods as the ancestral, unmodified form; the resemblance of the adult to an Annelid as the evidence of descent from an annelidan ancestor; the polyzoan larva of the hinged forms as a "falsification" of the embryological recapitulation of the ontogenetic process, and the resemblance

to a polyzoan as an acquired adapation which is not due to descent; or, on the other hand, we may regard the development of the hingeless Brachiopoda as the true ontogenetic record, and the direct conversion of the segmented embryo into the adult, in the hinged genera, as a syncopation of the record by acceleration of the time of acquisition by the young of the characteristics of the adult. In this case we must regard the resemblances of the adult Brachiopod to an Annelid as acquired adaptations, without morphological significance, and of the same character as the resemblance of an adult Tunicate to a Lamellibranch.

The association of the Brachiopods with the Annelids, on account of these resemblances would then be exactly comparable, so far as scientific value is concerned, with the old view that they are joined to the Lamellibranchs through the Polyzoa and Tunicata, and we should be compelled to search for evidence of the affinity of the Brachiopoda to other invertebrates, in the structure of the Polyzoa, and that of the segmented architrochic larva, but neither of these presents features upon which an affinity to the Annelids, as distinguished from many other invertebrates, could be founded.

As we can study the embryology of the existing species only, we cannot have any direct proof

of either of these alternatives, and must decide between them from the analogy afforded by the embryology of other groups of animals.

It is a well known embryological law, proved by observation, and capable of deductive demonstration, that the higher or more specialized forms of a group, frequently show a more or less marked tendency to jump some of the embryonic stages through which the lower forms pass. They all start alike, but the time of appearance of the adult characteristics, is "accelerated" in the higher forms, and the development thus simplified. The Cephalopoda among the Mollusca; certain Decapods among the Crustacea, and Salpa among the Tunicates, are well known examples.

As the hinged Brachiopods are much more specialized than the hingeless, the analogy of other groups would seem to indicate that the larval stage of the latter is ancestral, and the direct development of the hinged forms a secondary effect; but there is also an opportunity to cite analogy in support of the other view: that the larval stage of the hinged forms is an adaptation.

The chrysalis state of the Lepidoptera and other insects is a well-known instance of such acquisition of embryonic characteristics. While we should not expect the somewhat locomotive adult Lingula to have acquired a locomotive larval stage which has not been acquired by the entirely stationary

Terebratulina, we cannot deny the possibility of this, and we must test the question by a comparison of the larva with a Polyzöon, in order to decide whether the resemblances between them are superficial and such as we should expect to be brought about by similar conditions, or whether they are deep seated and of morphological value. We must compare the resemblances between the adult and an Annelid with those between the larva and a Polyzöon, in order to see which furnish the best proof of genetic relationship; which set of resemblances are latest, and grow most marked as the Lingula approaches maturity, and which are most embryonic and disappear as the specializations of the adult are acquired. As Morse is the most able advocate of the relationship of the adult to an Annelid, we may confine our attention to his statement of the case. In his summary, already quoted, p. 82, he lays especial stress upon the following resemblances of Lingula to a tubicolous Annelid; that it has a vermiform annulated peduncle; moves by sêtae, and makes a sand tube. The first of these resemblances is not real, as the peduncle of Lingula is not divided into segments; and the other two are certainly not features upon which it is safe to found a classification, for they are external adjustments to the environment, and precisely the sort of resemblances which are most easily brought about by adaptation.

On page 58, he gives in parallel columns, the following points of resemblance to the Vermes in general:

1. Vermes: Bilaterally symmetrical, depressed, flattened or circular, never flattened laterally.
   Brachiopods: Same.
2. Vermes: Above and below similar, or distinguished with difficulty.
   Brachiopods: Same.
3. Vermes: Most free, some attached.
   Brachiopods: Same.
4. Vermes: Muscles connected with integument, dorsally, ventrally and laterally.
   Brachiopods: Same.
5. Vermes: Two layers of muscles in body-wall.
   Brachiopods: Same.
6. Vermes: Digestive canal straight or seldom convoluted.
   Brachiopods: Same.
7. Vermes: Suspended in perivisceral cavity by bands of delicate tissue.
   Brachiopods: Same.
8. Vermes: Peculiar depuratory organs, consisting of bilaterally symmetrical tubes, opening externally, and communicating with the perivisceral cavity by ciliated infundibuliform orifices.
   Brachiopods: Same.
9. Vermes: Nervous system a simple œsophageal collar, with accessory ganglia, usually forming a chain.
   Brachiopods: Nervous system a simple collar.
10. Vermes: Generative products in most set free in perivisceral cavity.
    Brachiopods: Same.
11. Vermes: Possessing chitinous outgrowths, either as scales, or plates, or hairs, or spines, the latter being secreted by setigerous follicles.
    Brachiopods: Same.
12. Vermes: Cuticle perforated by minute pores.
    Brachiopods: Same.
13. Vermes: Perivisceral cavity ciliated in some cases.
    Brachiopods: Same in all cases.
14. Vermes: An extensive vascular system, containing a colored fluid, representing the pseud-haemal system. The corpusculated nutritive true blood is usually contained in the perivisceral cavity alone.
    Brachiopods: Same.
15. Vermes: Embryo distinctly transversely segmented.
    Brachiopods: Same.
16. Vermes: In some groups intestine having no anal outlet.
    Brachiopods: Same.

This is certainly a remarkable series of highly interesting resemblances, and is worthy of careful examination, but I think it proves much more and much less than the writer deduces from it.

In the first place, it will be noticed that the points given are not characteristics of the Annelids, but of the so-called "Class Vermes," and most naturalists are now agreed that the division Vermes is in no sense a natural group equivalent to such groups as the Mollusca, Echinoderms, or Annelids, but is a collection of numerous widely divergent forms of life, most of which are represented by a comparatively small number of subordinate groups, and accordingly have not been recognized as primary groups of equal morphological importance with those types which are represented by numerous modifications.

In pointing out that these various types of animal life, including the Brachiopods, have many features in common, Morse has done good service, and may claim to be a pioneer in that field of invertebrate morphology which has made the most important advances within the five years since the publication of his paper.

This period has been especially marked by the comparisons and generalizations which have been made from the mass of embryological and anatomical knowledge which had been accumulated during previous years. As the result of this com-

parison, we now know that not only the "Vermes" and Brachiopods, but the Echinoderms, Mollusca, Vertebrates, in fact all the Cœlomatous Metazoa, have so many points in common as to indicate that they are all branches which diverged, very early, from a common bilaterally symmetrical worm-like form, but I do not think that the points above quoted, justify us in regarding the Brachiopods as more intimately associated with the "Vermes" than other groups, such as the Echinoderms and Mollusca.

Of the points quoted the 1st, 2d, 3d, 11th and 12th are plainly superficial and of little morphological value. Prof. Morse appears to attach great importance to the 11th, but even if chitinous setae could be shown to be confined to the Chaetopod worms and Brachiopods, which is certainly not the case, this fact in itself would not be of any greater importance than the fact that calcareous spicules are found in the Sponges, Echinoderms and some Nudibranchs. The 4th, 5th, 6th, 7th, 10th, 13th and 16th are all of them points which are not at all generally true of the so-called "Vermes," and none of them are confined to the animals which have been included in that group; for instance, the 4th, 5th, 6th, 7th, 13th and 16th hold true of certain Echinoderms, and the 4th, 5th, 6th, 7th and 13th apply to the Holothurians; most of them are also true of some Mollusca, and nearly all of

them are true of most Tunicates. With regard to the 9th point, the nervous system of an Echinoderm consists of a single œsophageal nerve ring, with accessory fibres; and we now know from the investigations of Von Jhering that the molluscan nervous system is fundamentally like that of an Annelid. The 10th peculiarity is not at all uncommon, and is true of most Vertebrates for instance. There remain then only the 8th and 14th points upon which to base the claim to a peculiar and especial affinity between the Brachiopoda and the Vermes. The resemblance in these particulars is undeniable and of the greatest interest, and five years ago was almost enough to establish Morse's view, but one of the most remarkable recent contributions to morphology—the result of numerous investigations by different observers—is the proof that the depuratory organs of nearly all of the Cœlomatous Metazoa are fundamentally alike.

To quote from Lankester (Notes on Embryology and Classification:)

"In Rotifera, Flat Worms, Gephyraea, Mollusca, in the metameres of Chaetopoda, in the Vertebrata, and even in some Arthropoda, we have evidence of the existence of a single pair of canals, more or less highly modified by glandular developments, which usually open by ciliated funnel-like mouths into the cœlom at one end and directly to the exterior in the neighborhood of the anus, or into a cloacal chamber, at their other end, thus placing the cœlom in communication with the exterior. This pair of ciliated funnels appears to be the same organ in all cases."

It is plain then that at the present time the presence of these organs in the Brachiopod cannot

be held to show any peculiar affinity to the "Vermes."

There remains then only the 14th point, and it is only necessary to call attention to the presence in the Echinoderms of a corpusculated perivisceral fluid, and a pseud-haemal system restricted to vessels, in order to show that this resemblance is too general to indicate the supposed close relationship. The segmented embryo I have already spoken of. The Brachiopods then are "Vermes" in the same sense that the Echinoderms, Mollusca, Tunicates and Vertebrates are, and in order to include them we must make the word almost synnonomous with "Cœlomatous Metazoa."

In the case of the Brachiopods and Polyzoa on the other hand we have a resemblance which is definite and minute; which is most marked during the youngest stage of development, and gradually becomes less conspicuous as the adult characteristics are acquired, and there appears to be every reason to conclude that the relation of the Brachiopoda to other invertebrates must be traced only through the Polyzoa.

Accepting then the relationship of the Polyzoa and Brachiopoda as proved, and recognizing the fact that the former is the ancestral form of which the latter is a specialization, we come now to the question: to what other forms are the Polyzoa most nearly related? There is certainly a great

general resemblance between a hippocrepian Polyzöon and a Rotifer, but there is also a fundamental difference in certain highly important particulars; for instance, the nervous system and bend of the tentacular crown are between the mouth and the anus in the Polyzöon, and on the side opposite the mouth in the Rotifer. In the former, the mouth is inside the crown of tentacles, and the latter is therefore "architrochic," while it is "cephalotrochic" in the latter, or with the mouth outside the circle. The resemblance between the two is very close however, and should find expression in a system of classification; but I think that the resemblance between a Polyzöon and the molluscan Veliger, is much more detailed and complete, and the relationship closer. In a paper upon the affinity of the Mollusca and Molluscoida, (Boston Soc. Nat. Hist., Feb. 2, 1876,) I attempted to show that the various groups of true Mollusca are related to each other, not through the Lamellibranch, but through the Veliger; and then gave the following statement of the affinity of the Veliger; a statement which I still regard as the true view:

Most of the Gasteropoda are known to pass through a free, locomotive "Veliger" stage. The Veligers of different Gasteropods differ considerably in form; and in some, the embryo at this stage, is much less specialized than in others; but, omitting the complications introduced as adaptations to a spiral shell, the Veliger of such a marine Gasteropod as Astyris, may be regarded as presenting the typical form. A Veliger may be described as a free-swimming, bilaterally symmetrical embryo,

without a true heart or vascular system, or branchiæ, with the mouth and anus near each other on the median line. The digestive organs are suspended in the body-cavity, and attached to the body-wall at the two external apertures, and by the various muscles. The foot is situated between these two openings; and the pedal ganglia, which are in most Veligers the first ganglia to appear, are developed in the region of the foot; that is, between the mouth and the anus. The foot is generally supplied with a bunch of setae, which are apparently sensory in function. The animal is enclosed in a shell composed of two portions; a large ventral cup, and a neural or pedal operculum, which is united to the anal margin of the cup at the earliest stages, and subsequently becomes separated from it This shell and lid are found in the embryos of those forms where the adult is without an operculum, as Crepidula, as well as in those where the adult is destitute of a shell, as the Nudibranchs.

The most characteristic peculiarity of the Veliger is the *velum*. This is a large bilaterally symmetrical circlet of cilia, developed from the cephalic region of the embryo, and supported, at some distance from the body, by a transparent double-walled veil, the cavity of which is irregularly divided into large sinuses, in free communication with the body-cavity. The animal swims, usually near the surface of the ocean, by means of the long cilia of the velum, which would seem to perform the function of a respiratory organ as well, for the fluid which fills the body-cavity is driven into and out of the sinuses of the velum by the retraction and expansion of this structure; in most Veligers this circulation seems to be aided by the rythmical contraction of the muscular fibres which bind the foot to the œsophagus. The mouth is not within the circlet of large locomotive cilia, but immediately behind it, and a ring or band of smaller cilia passes from the anterior margin of the mouth entirely around the velum, on its lower surface, and therefore outside the circlet of locomotive cilia.[1] This second circlet seems adapted to convey food to the mouth, but there are no direct observations upon this point. The velum and the foot are retracted into the shell by the action of a pair of long muscles which pass from the sides of the œsophagus and region of the foot to the bottom of the ventral shell, and subsequently become the columellar muscle of the adult.

The conclusion to be drawn from our present knowledge of the Mollusca, will appear to be that all of them are to be traced back to a free-swimming ancestral form, of which the Veliger embryo is the representative; this seems to be the only way in which we can account for its appearance in at least certain representatives of so many widely separated groups.

We come now to the interesting question: what are the affinities of this "Veliger" from which the true Mollusca are descended?

[1] Since the paper quoted was written, I have observed this second band of cilia, which passes behind the mouth, in a number of Gasteropod Veligers.

It is only necessary to glance at the side view of any fully developed Veliger, such as Selenka's figure of Tergipes, in order to notice the resemblance to a Polyzöon, and more careful examination shows that the resemblance holds not only in the general plan but in detail. The velum corresponds to the lophophore in position and structure, and subserves, like this, the function of respiration, and probably that of ingestion a well. The heart is absent in both, and the fluid which fills the body-cavity and bathes the digestive organs is kept in motion by the contraction of the various muscles of the body. The digestive organs are similar in form and also in their connections. The epistome with its ganglion answers to the foot and pedal ganglia, and in Rhabdopleura the epistome is functionally as well as morphologically a creeping disc. The shell and operculum answer to the cell and lid of a cheilostomatous Polyzöon, and the retractor muscles are clearly homologous. The most important differences seem to be that among the Polyzoa, the animals are fixed and multiply by budding; and that in all, the mouth, as well as the epistome, is within the circlet of the lophophore. (Rhabdopleura was described by Allman as an exception in this respect: Sars, however, has shown that although the tentacle-bearing portion comes to an end upon the sides of the foot, the line of cilia is continued entirely around it.) The lack of agreement between the positions occupied by the mouth and foot in the two forms seems to be the most serious objection which can be urged against the view here advocated. In answer to it we can only point out that in Dentalium the mouth is formed within the circlet, although the foot is outside it. It is not to be supposed, however, that the Veliger can be traced back to any existing form of Polyzöon, or even to any order of this class. In some respects its affinities are with the Hippocrepia, in others they are with the Cheilostomata, and in still others they are with Rhabdopleura, and they therefore indicate that the common ancestral type of the Mollusca was not a true Polyzöon, but simply a Polyzöon-like form. A lack of agreement in points of detail is therefore no more than we should anticipate. In answer to the second objection, that the Polyzoa multiply by budding, we may refer to the well known law, that agamic vegetative multiplication is antagonistic to high evolution, and is accordingly replaced by true sexual reproduction in the higher forms of all classes of animals; as its presence, if it occurred in any of the true Mollusca, could not be regarded as proof of an affinity to the Polyzoa, its absence does not disprove such affinity. No one will attach much importance to the remaining objection, that the Polyzoa are fixed.

The similarity between the Polyzoa and true Mollusca, in general plan of structure, has long been recognized, but the attempts to connect the two groups through the Lamellibranchs are so evidently incorrect that, led by the unquestionable affinity of the Polyzoa and Brachiopods to the Vermes, many geologists are now inclined to separate these lower forms from the Mollusca proper. As soon as we recognize that the Lamellibranchs are not to be regarded as typical Mollusca, and that all of the

latter are to be traced back to a "Veliger" all difficulty seems to disappear, and it becomes plain, not only that Mollusca and Molluscoida are related, but that they are connected so closely, that the advisability of such a division is very doubtful. We also obtain, at the same time, an explanation of the worm-like early stages of the embryo, exhibited by so many of the true Mollusca. The belief so firmly supported by nearly all zoölogists a few years since, that the various branches of the animal kingdom are absolutely independent of each other, has been almost entirely overthrown by the accumulation of new facts, and the constantly increasing tendency to examine them in their bearing upon the theory of the evolution of life; and the union or junction of the Vermes and the Mollusca, in some manner, has already found a number of advocates.

Prof. Morse, by his investigations upon the anatomy and embryology of the Brachiopods, has shown that, if we consider this group by itself, it must be placed with the Annelids. His investigations also show, with equal clearness, that the Brachiopoda are closely related to the Polyzoa, and we must therefore regard them as united by the "Veliger" to the true Mollusca. If we accept the view that the molluscan and vermian stems are thus united, the question,—"Are the Brachiopods Worms or Mollusks?"—will be regarded as nothing but a verbal discussion; for this class forms the connecting link between the two groups, and any sharp line of demarcation does not exist.

In the above paper, I proposed a provisional phylogeny of the Mollusca, which I should now accept only after considerable modification.

The Rotifera, Polyzoa and Veliger, seem to be three branches which diverged, very early, from a common vermian stem. The Brachiopoda are the most highly specialized representatives of the Polyzöon branch, and the true Mollusca stand in a similar relation to the Veliger branch. The three stems appear to be sufficiently closely related to each other, and sufficiently sharply distinguished from all other animals to constitute by themselves one of the fundamental divisions

of the animal kingdom, which might be called, on account of the conspicuous character of the trochal disk, the Trochifera.

In conclusion, I may be allowed to call attention to the obvious fact, that the persistence of Lingula, entirely without change, for a period which is too great to be measured in the terms of such a unit as the length of human experience, is a very forcible instance to show that the facts of zoölogy absolutely forbid the acceptance of any theory of necessary evolution by continuous progress from homogeneity to heterogeneity.

EXPLANATION OF THE FIGURES.

With the exception of Figure 16, the letters of reference have the same significance throughout, but this is not true of the numbers.

A. Dorsal or aboral valve of shell.
B. Ventral or oral valve.
C. Peduncular or posterior end of shell.
D. Anterior end.
a, a. Hinge-teeth of aboral valve.
b, b. Hinge-teeth of oral valve.
c. Semicircular plate of aboral valve.
d. Median or aboral tentacle.
d^1, d^1. The pair of oral tentacles.
d^2, d^3, d^4, d^5, &c. The tentacles of one side numbered according to their order of appearance.
d^n. The most recent pair of tentacles, in process of development at the sides of the aboral tentacle.

e. The lip, formed by a crescent-shaped fold of the oral surface of the lophophore.

f. Lateral walls of the body, (*parietal bands*.)

g. Body-cavity.

h. Liver.

i. Œsophagus.

k. Hepatic chamber of stomach; the "cardiac" chamber of the Polyzoa.

l. Intestinal chamber of stomach; the "pyloric" chamber of the Polyzoa.

m. Intestine.

n. Anus.

o. Mouth.

p. Muscles which pass from one valve to the other on each side of the œsophagus near its union to the stomach; they occupy the same position as those muscles of the adult which in the figures (after King) of the article "Brachiopoda" in the Encyclopædia Britanica (ninth ed., vol. 4, p. 193, Figs. 23, 24 and 25,) are lettered *hh*; but during the larval stages they probably resemble not these muscles alone, but also those lettered *jj*, *kk* and *ll* in the above article.

q, *q*. The lophophore.

r. Posterior unpaired muscle, (*g* in the article above referred to.)

s. Peduncle.

s'. Free end of peduncle.

s''. Cavity of peduncle.

t. Pallial cavity.

u. Ventral end of the muscle, *j*, of the article "Brachiopoda."

u''. Dorsal end of the muscle, *i*, of the same article.

u'. Dorsal end of a muscle which probably represents the adult muscles *k* and *l*, in the same article.

v. Pallial sinus.

w. Its opening into the body-cavity.

x. Ventral portion of nerve ring.

x'. Œsophageal commissure.

x''. Ganglionic enlargement of x'.
x'''. Otocyst.
y. Retractor muscles.
z. Reflection of dorsal portion of the body-wall onto the inner surface of the shell.

PLATE I.

FIGURE 1.—Dorsal view of the youngest larva which was figured, magnified 250 diameters, (Zeiss Obj. D.; Eye-piece 2.) The vase-shaped body, containing the digestive organs, occupies the middle line, and the integument adheres closely to the surface of the stomach and liver, thus almost obliterating the body-cavity. At its upper end the œsophagus bends towards the ventral surface, and the mouth, *o*, is seen through its transparent wall. The lophophore carries five pairs of tentacles, besides the single median dorsal tentacle, *d*. Posterior to the mouth the lophophore is below or ventral to the œsophagus. Above the mouth the lip, *e*, is seen through the transparent lophophore. The pallial space is a capacious chamber, *t*, *t*, *t*, on the sides of and in front of the animal.

FIGURE 2.—A little older larva, magnified 250 diameters, and seen from the ventral side. The intestine, *m*, is seen opening into the pallial chamber on the right side of the body. The integument is separated from the surface of the digestive organs, by a distinct body-cavity, *g*. On the right side of the posterior end of the body, the peduncle, *s*, has appeared. The ciliated mouth, *o*, and lip, *e*, are here shown in surface view in the centre of the lophophore, which now carries eight pairs of tentacles on each side.

PLATE II.

FIGURE 3.—Dorsal view of a somewhat older embryo, seen with the same magnifying power. The drawing has

been somewhat reduced, but as the line, *aa*, has the same absolute length in all the larvae, the increase in size may be seen by comparing this line in Figures 2 and 3. The shell has elongated, and the thickened margin of the mantle has begun to develop setae. The peduncle has increased greatly in length, and is folded across the posterior end of the body, and does not project from the shell. The body-cavity is now quite conspicuous, and the integument is quite widely separated from the surface of the digestive organs. The nerve ring and otocysts are now seen around the anterior end of the stomach; the number of tentacles has increased to ten pairs, and the sides of the lophophore begin to fold towards the dorsal surface.

FIGURE 4.—Dorsal view of the body of the larva shown in Figure 2, somewhat compressed and magnified 740 diameters, (Zeiss, D. 4.) The stomach, *k*, *l*, and liver, *h*, have been somewhat flattened by pressure, thus obliterating the body-cavity, which should be visible between the surfaces of these organs and the integument, *f*. The dorsal ends of the adductor muscles, *p*, have also been pushed over the œsophagus by the pressure. The otocysts, x''', the lateral ganglia, x'', and the ventral ganglion (seen through the œsophagus,) are shown, but the commissure, x', does not yet encircle the digestive tract.

PLATE III.

FIGURE 5.—Ventral view of the body of a larva of about the same age as that shown in Figure 3. The ventral nerve mass, *x*, is shown upon the œsophagus. The integument is widely separated from the digestive organs, and the ciliated body-cavity is filled with blood corpuscles, as is also the ciliated cavity of the peduncle. From the anterior end of the ventral surface of the body, two long horn-like diver-

ticula from the body-cavity penetrate the mantle of the ventral valve, and run forwards, forming the pallial sinuses, *r*. They are ciliated, filled with blood corpuscles, and communicate with the perivisceral space by large funnel-shaped ciliated apertures, *w*.

FIGURE 6.—Dorsal view of the same larva. The nerve ring, x', the lateral ganglion, x'', and the otocysts, x''', are shown between the integument and the digestive tract; and the integument bulges outwards on each side, over the lateral portions of the nervous system.

PLATE IV.

FIGURE 7.—Ventral view of a small Lingula soon after it becomes sedentary; the actual length of the shell is shown by the short line at the right; and the relative size as compared with Figure 3, by the line, *nu*, the edge of the larval shell. The tentacles are now 16 in number on each side, and the lateral margins of the lophophore begin to bend towards the dorsal surface. At this stage the shell was too opaque to allow of the minute examination of the digestive organs, which are only shown in outline.

PLATE V.

FIGURE 8.—The same embryo in a dorsal view, with the dorsal valve, *B*, displaced by rotation upon the body. The bending of the lateral edges of the lophophore is well shown at *q*, *q*.

PLATE VI.

FIGURE 9.—Dorsal view of the posterior end of the body of an embryo a little older than Figure 1, to show the relation of the peduncle to the body-wall; greatly magnified.

FIGURE 10.—Ventral view of the same embryo.

FIGURE 11.—Ventral view of the same organs at the stage shown in Figure 2.

FIGURE 12.—Blood corpuscles of adult Lingula.

FIGURE 13.—A portion of the lophophore.

FIGURE 14.—A single tentacle, more highly magnified.

FIGURE 15.—Proximal ends of three tentacles.

FIGURE 16.—Diagram of longitudinal section of the embryo, at about the stage shown in Plate 2, Figure 3.

a. Tips of valves.
b. Thickened margin of mantle.
c. Mantle.
d. Dorsal median tentacle.
e. Lophophore.
f. Lip.
g. Mouth.
h. Mouth cavity.
i. Body-cavity.
k. Wall of œsophagus.
l. Œsophagus.
m. Hepatic chamber of stomach.
n. Intestinal chamber of stomach.
o. Intestine.
q. Ventral ganglion.
r. Posterior muscle.
s. Dorsal valve of shell.
t. Ventral valve of shell.

FIGURES 17 and 19.—Embryo of Thecidium, from Lacaze-Duthiers.

FIGURES 18, 20 and 21.—Polyzōon embryos, from Barrois.

Development of Lingula. **Plate 1.**

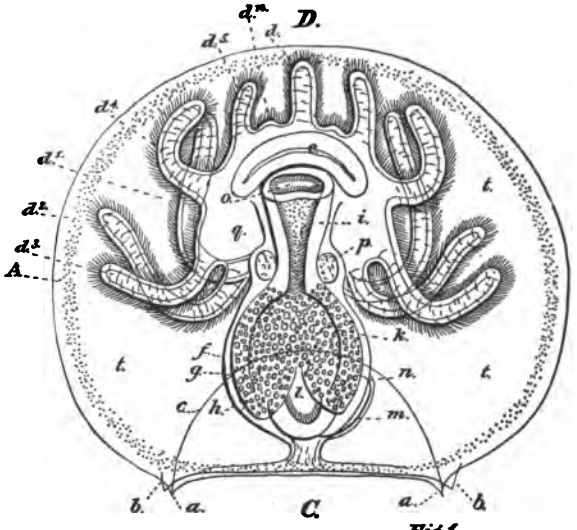

Fig 1.

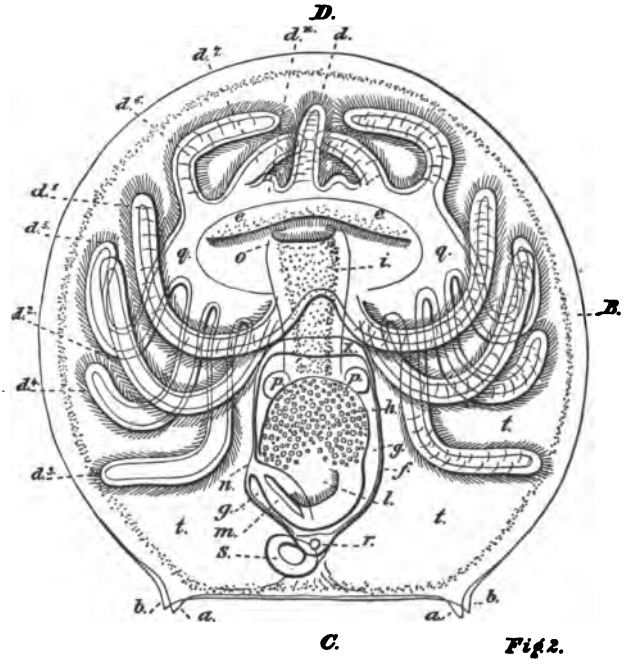

Fig 2.

W. K. BROOKS, DEL.

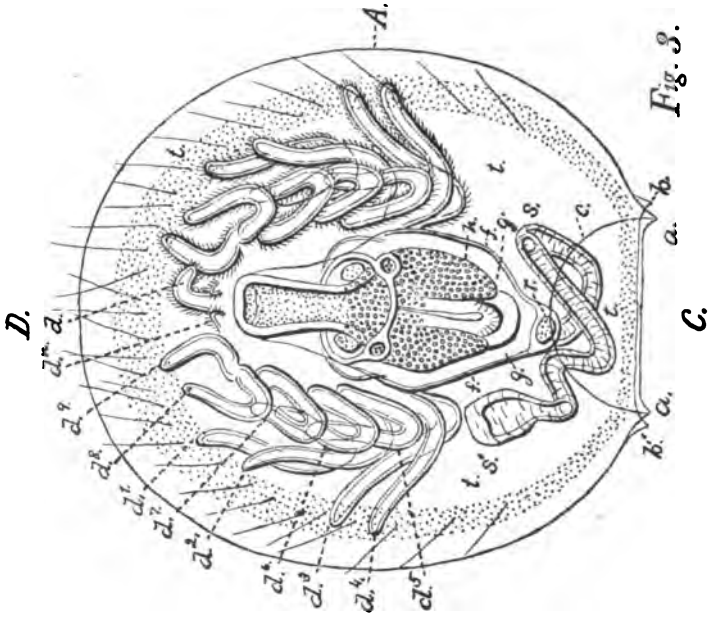

Fig. 3.

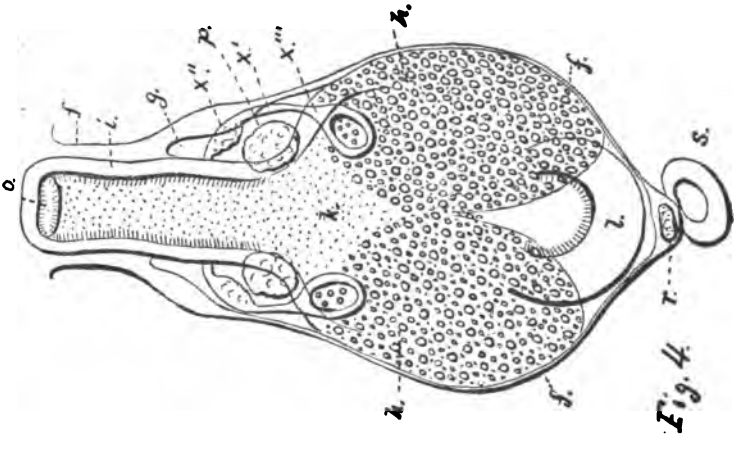

Fig. 4.

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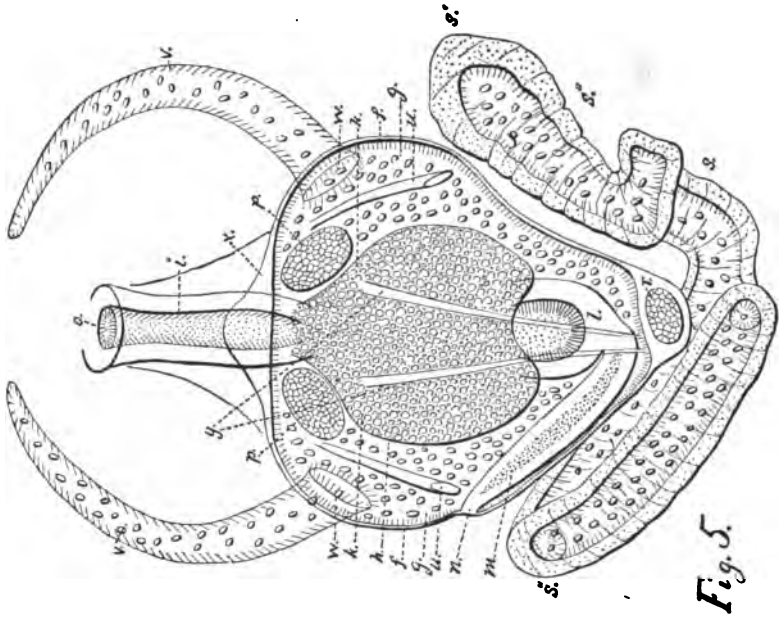

Fig. 5.

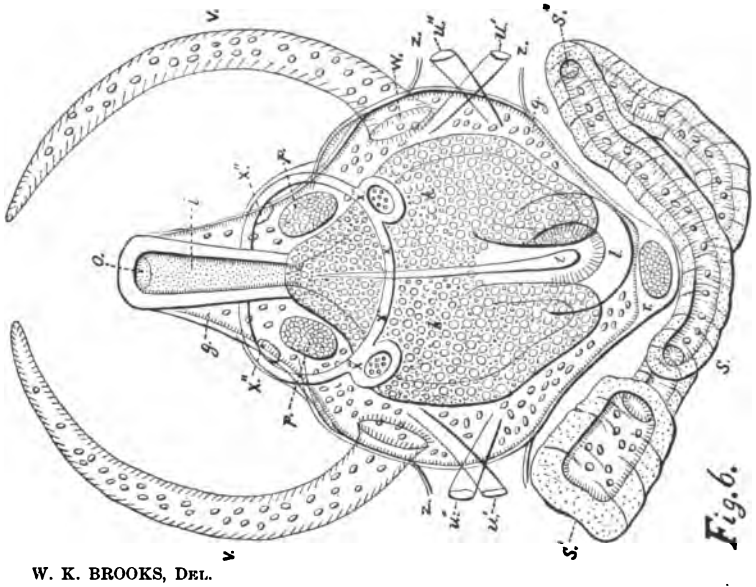

Fig. 6.

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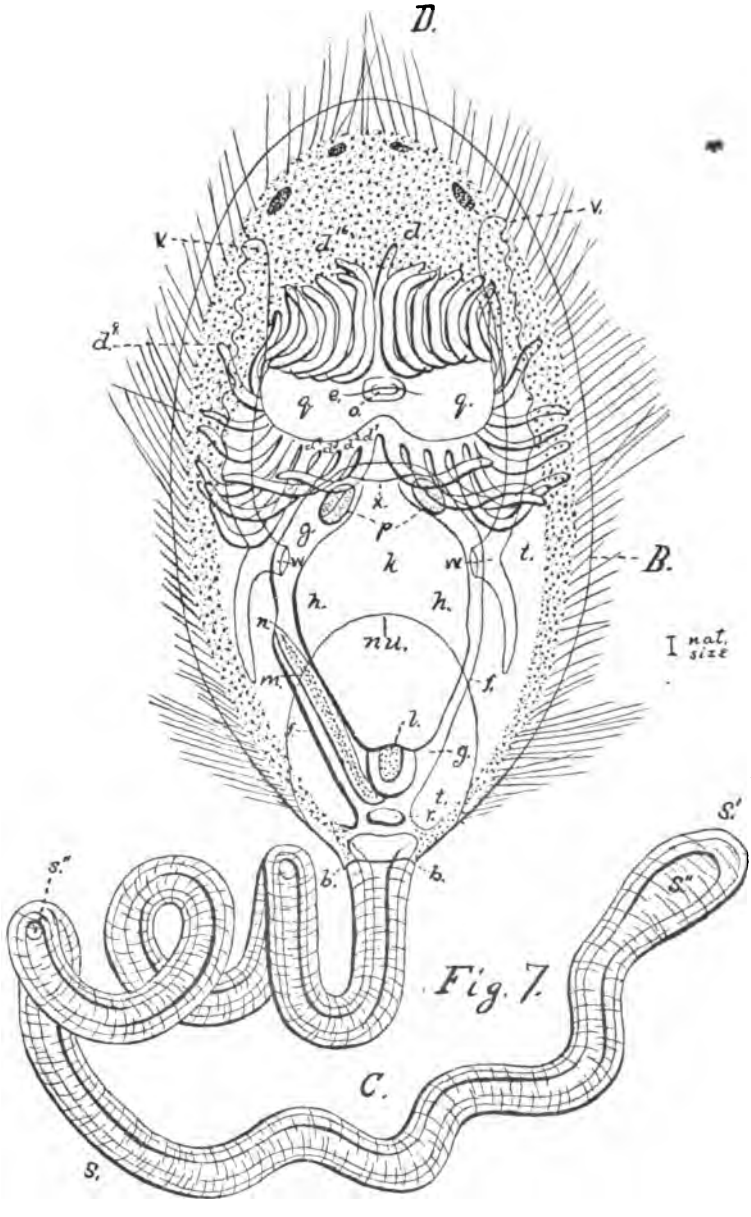

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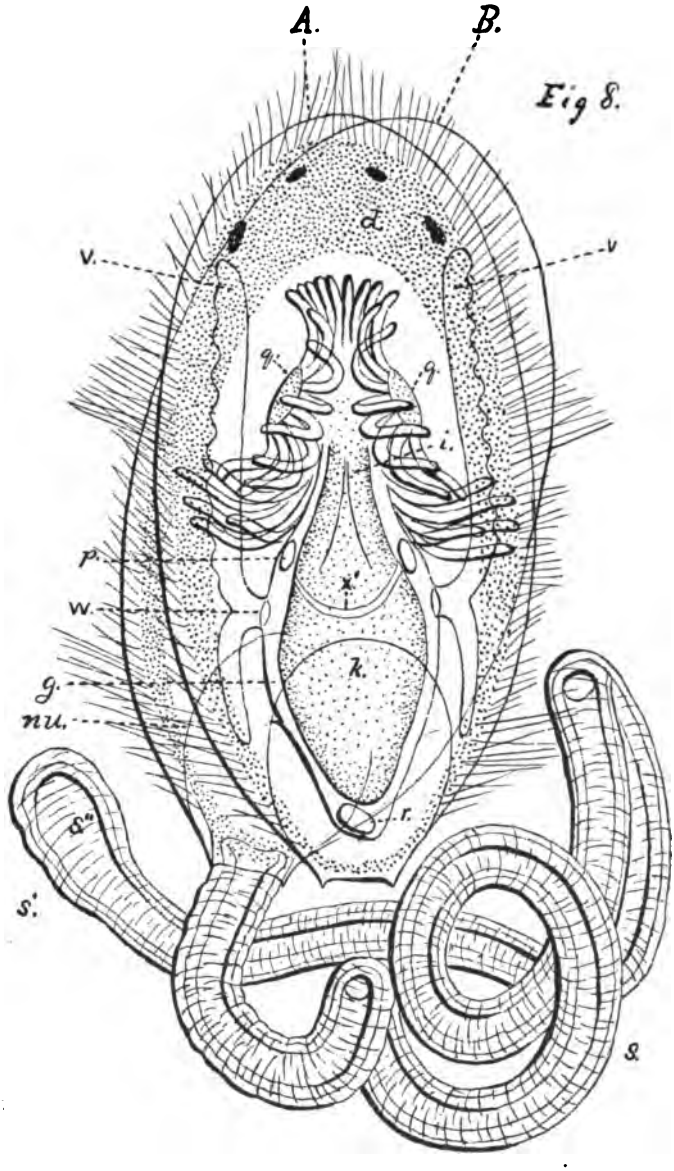

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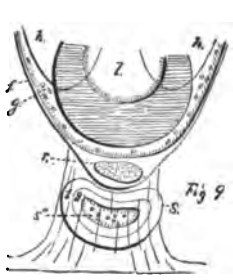


Fig 9

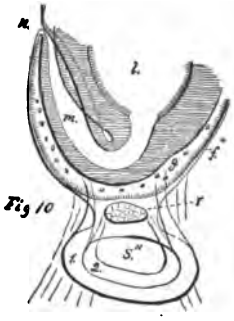


Fig 10

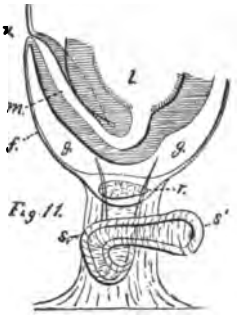
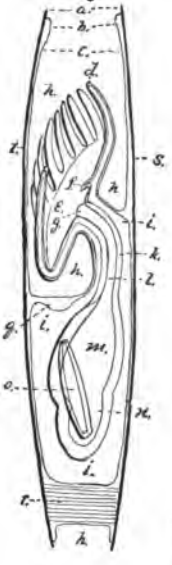


Fig 11.

Fig 16.



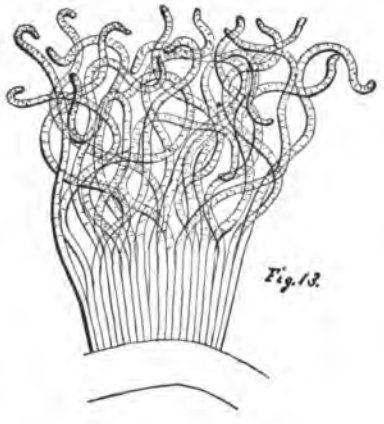


Fig. 13.

Fig. 14.

Fig 12.

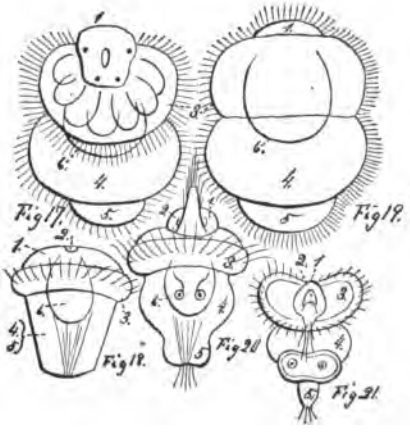


Fig 17. Fig 19.

Fig 18. Fig 20. Fig 21.

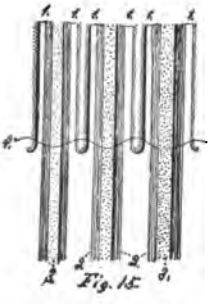


Fig. 15.

Description of Lucifer Typus. M. Edw.?

By Walter Faxon, *Museum of Comp. Zoölogy of Harvard College.*

During the early part of August a few specimens of the genus Lucifer were taken at night with the hand net, at the surface of the water, in the vicinity of Fort Wool, by Mr. August Schmidt.

As far as I know, this is the first record of the occurrence of this interesting genus on our shores. Messrs. Smith and Harger took a few specimens (species undescribed and undetermined) east of George's Bank, Lat. 41° 25′ N., Long. 65° 5′ to 30′ W., (Note 1.) The described species have come from various points in the Mediterranean, Atlantic, Pacific and Indian Oceans.

Description.

Antennary segment twice as long as the carapace. A small spine (Figure 1, *s*′,) projects from its anterior margin at the base of the eye-stalks.

There is no clear line of demarcation between the antennary segment and the carapace.

Carapace about as long as the first abdominal segment. Its inferior borders crenate. A minute spine on each side. (Figure 1, ζ.)

The first five segments of the abdomen are about equal in size, their latero-inferior margins produced into an obtuse angle at the middle. The sixth segment of the abdomen is almost twice as long as the preceding ones, and is furnished with two teeth on the lower border on either side; the anterior tooth is pointed; the posterior, blunt.

The eye-stalks are clavate, and less than one-half as long as the antennary segment.

The peduncle of the first antennae is composed of a basal segment nearly equal in length to the ocular peduncle, and two short segments. The proximal end of the basal segment is slightly enlarged for the accommodation of the auditory sac with its enclosed otolith. (Figure 1, ε.) (Note 2.) The peduncle bears a long multiarticulate flagellum, the proximal annuli of which are furnished with short setae.

The peduncle of the second antennae is composed of two segments. Of these, the first is very short, and bears a short "olfactory denticle." The second segment is much longer, but not equal to the proximal segment of the first

antennae. The flagellum is apparently about as long as the flagellum of the first pair. The second antennae bear at their base, externally, an "antennal scale," (Figure 1, *d*,) which is fringed with numerous setae, and equals the eye-stalks in length.

The mouth is bounded in front by a large labrum, (Figure 1, *e*; Figure 2, *a*,) then follow a pair of mandibles, (Figure 2, *b*,) and a bilobed metastoma. (Figure 2, *c*.) The first maxillae consist of a small setiferous inner lobe, (Figure 2, *d''*,) a larger outer lobe (Figure 2, *d'*,) also armed with setae, and a palpus. (Figure 2, *d'''*.) The second maxillae (Figure 2, *e'*,) possess a "scaphognathite," (Figure 2, *e''*,) but their structure was not made out in detail. The first maxillipeds (Figure 2, *f*,) are two-jointed, the terminal segment beset with setae on its inner border.

The second maxillipeds (Figure 1, *f*, Figure 2, *g*,) are made up of six segments, the three distal bent back upon the preceding ones. All the segments of this appendage and the four following pairs bear scattered setae.

The four following pairs of appendages (third maxillipeds and first, second and third "decapodal" legs,) are bent forward. The second pair is the shortest, next in length comes the first pair, next the third, the last being the longest, and furnished with a minute claw at the extremity.

There is no trace of the fourth and fifth pair of "decapodal" legs, nor of outer branches on any of the thoracic pairs.

The first pair of abdominal appendages in this (male) specimen are armed with the peculiar prehensile organ (Figure 1, *m'*,) which is commonly found in the males of this genus. It consists of a movable piece (Figure 3, *a*,) which closes upon a blunt process, (Figure 3, *b*,) tipped with minute teeth. There is but one terminal branch.

The second pair of abdominal appendages have three terminal branches, (Figure 1, *n'*, *n''*, *n'''*,) the remaining four pairs possess two terminal branches. The outer branch of the last pair (Figure 1, *r'*,) is longer than the inner branch, (about one-third longer than the telson,) and is produced at postero-lateral angle into a sharp tooth. The terminal branches of all the abdominal limbs are furnished with setae, excepting the short plate-like third branch of the second pair, (Figure 1, *n'''*.)

Length, 9 millimetres.

The single specimen obtained agrees in most respects with the description of the earliest known species by J. R. Thompson, (Note 3.) It differs noticeably, however, in the shorter eye-stalks. In this it agrees better with *Lucifer Regnaudii*, M. Edw., (Note 4.) In view of the unsatisfactory description of the known species, I have thought best not to impose a new specific name upon this

specimen until sufficient material is at hand for a critical revision of the species.

CAMBRIDGE, *January 9th, 1879.*

NOTES.

1. Report on the Dredgings in the region of St. George's Banks, in 1872. By S. J. Smith and O. Harger. Trans. Conn. Acad. Arts and Sci., III, 26, 1874.

2. The auditory apparatus of *Lucifer* was first observed by SOULEYET, (Comptes Rendus, XVII, 665, *note*, 1843; Froriep's Neue Notizen, XXVIII, 84, *note*, 1843.) Later it was described and figured by HUXLEY. (Notes and Observations made on board H. M. S. Rattlesnake during the years 1846–50. Ann. Mag. Nat. Hist., 1851, p. 305, Pl. XIV, Fig. 1.) *Cf.* also, KRÖYER, Forsög til en mongruphisk Fremstilling af Kræbsdyrslægten Sergestes. Med Bemærkninger om Dekapodernes Horeredskaber. Kong. Dansk. Vidensk. Selsk. Skrifter. V, Naturvidensk og Math., Afd. IV, 293, Tav. V, Fig. 20, 1859. HEUSEN, Studien über das Gehörorgan der Decapoden. Zeits. Wiss. Zool., XIII, 383, 1863.

3. Zoölogical Researches and Illustrations, p. 58, Pl. VII, Fig. 2, 1829. Thompson's specimen was taken in the Atlantic, Lat. 11° 56′ N., Long. 32°

55′ W. He described it under the generic name simply. The trivial name *typus* was given later by Milne Edwards, (Hist. Nat. des Crustacés, II, 469, 1837.)

4. *Loc. cit.*, Pl. 26, Fig. 10. From the Indian Ocean.

Besides the above cited works, *cf.*, with reference to *Lucifer*, DANA, Crust. U. S. Explor. Exped., pp. 668–675, Pl. 44, Fig. 9; 45, Figs. 1–3, 1852.

SEMPER, Zeits. Wiss. Zool., XI, 106–107, 1862.

CLAUS, Ueber einige Schizopoden und niedere Malacostruken Messina's. Zeits. Wiss. Zool. XIII, 433–437, Taf. XXVIII, Fig. 21–26, 1863.

A. DOHRN, Untersuchungen über Bau und Entwickelung der Arthropoden. Zeits. Wiss. Zool., XXI, 356–359, Taf. XXVII, Fig. 1–10, 1871.

WILLEMÖES-SUHM, "Preliminary Remarks on the Development of some Pelagic Decapods." Ann. Mag. Nat. Hist., XVII, 163, 1876. (An interesting note on the development of *Lucifer*, showing that Dana's genus *Erichthina* is a young stage of *Lucifer*. See also, CLAUS, Untersuchungen zur Erforshung der genealogischen Grundlage des Crustacien-Systems, p. 40, 112, 113, 1876.)

STREETS, Contr. to the Nat. Hist. of the Hawaiian and Fanning Islands and Lower California Bull. U. S. National Museum, No. 7, p. 122, 1877.

Lucifer typus. *Plate 7.*

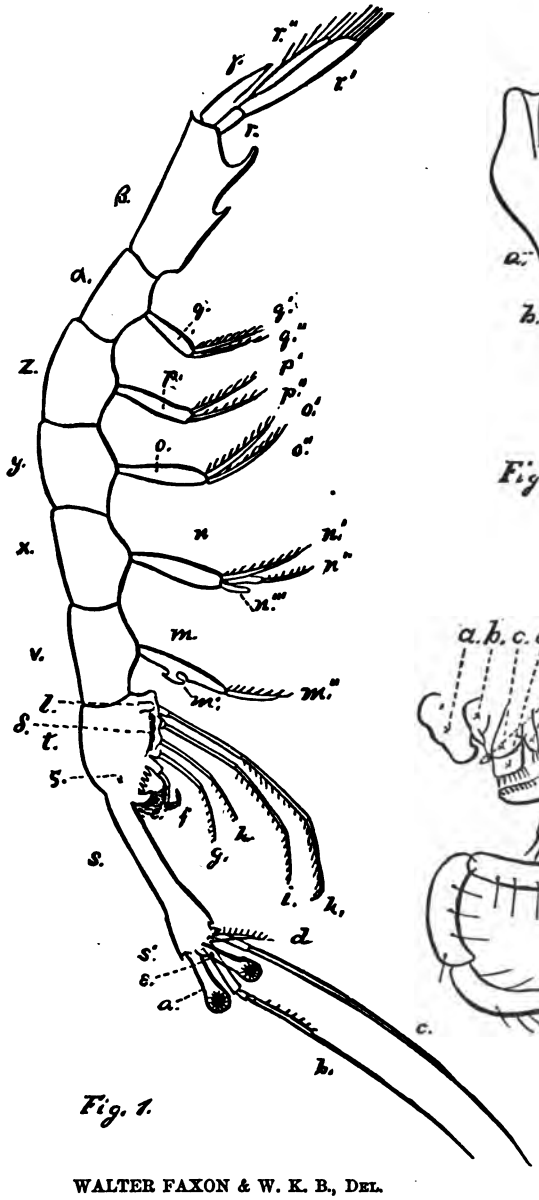


Fig. 1.

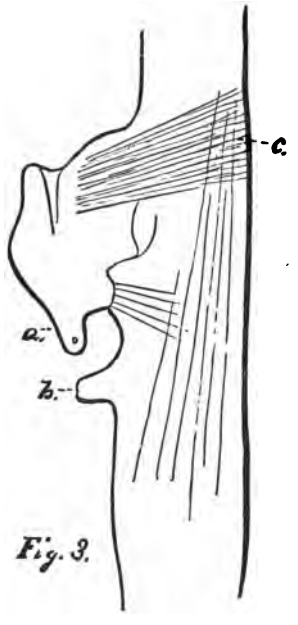


Fig. 3.

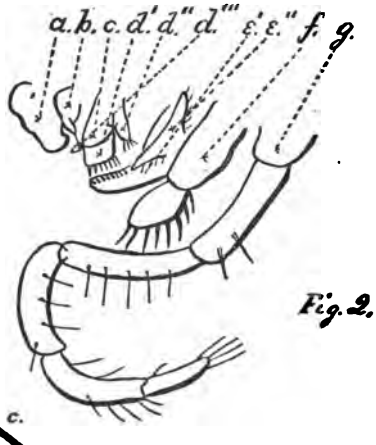


Fig. 2.

WALTER FAXON & W. K. B., DEL.

EXPLANATION OF FIGURES.

FIGURE 1.—*Lucifer typus* M. Edw.? 9 mm. in length. *a*, eye-stalk; *b*, antenna of first pair; *c*, antenna of second pair; *d*, "scale" of second antenna; *e*, labrum; *f*, second maxilliped; *g*, third maxilliped; *h*, *i*, *k*, appendages corresponding to the first, second and third pairs of legs of the higher Decapods; *l*, sac at the end of the *vas deferens*? *m*, first abdominal appendage; *m'*, copulatory organ on the first abdominal appendage; *m''*, terminal branch of the first abdominal appendage; *n*, *n'*, *n''*, *n'''*, second abdominal appendage with its three terminal branches; *o*, *p*, *q*, third, fourth and fifth abdominal appendages with their two terminal branches; *r*, *r'*, *r''*, basal segment, outer and inner branches of the sixth abdominal appendage; *s*, antennary segment; *s'*, spine on antennary segment; *t*, carapace; *v*, *x*, *y*, *z*, *α*, *β*, first to sixth abdominal segments; *γ*, telson; *δ*, nervous cord in the thorax; *ε*, auditory organ in basal segment of first antenna; *ζ*, spine on the carapace.

FIGURE 2.—Do. Mouth-parts of left side. *a*, labrum; *b*, mandible; *c*, metastoma; *d'*, outer lobe of first maxilla; *d''*, inner lobe of first maxilla; *d'''*, palpus of first maxilla; *e'*, second maxilla; *e''*, scaphognathite; *f*, first maxilliped; *g*, second maxilliped.

FIGURE 3.—Do. Prehensile male organ on the anterior border of the first pair of abdominal appendages, $\frac{1}{4}$ inch objection. *a*, movable piece which closes upon the process *b*; *c*, muscles which move *a*.

Preliminary Observations upon the Development of the Marine Prosobranchiate Gasteropods.

By W. K. Brooks.

The segmentation of the egg among the Mollusca, and the early stages of development in the various groups, present so many variations that it is of the greatest importance that at least an outline of the process should be published for as many forms as possible.

During the summer of 1877 I made use of the opportunities which the laboratory of the United States Fish Commission at Wood's Hole afforded for studying the development of certain Marine Gasteropods, whose eggs are characterized by the presence of a large food yolk and the restriction of the segmentation to one pole of the egg. While my observations agreed in many points with those of Brobetsky, ("Studien über die embryonale Entwickelung der Gasteropoden," Arch. f. Mic. Anat., 1876,) my interpretation of the phenomena was totally opposite in certain important particulars. According to this observer, the mouth and foot are formed at that pole of the egg where the blastoderm finally closes together to surround the food yolk, and the definitive mouth is similar in position to the gastrula mouth. According to my observations, the mouth and foot appear upon that pole

where the segmentation commences, and the gastrula mouth coincides, in position with the shell gland.

During the past summer, at Fort Wool, I reviewed the subject thoroughly and satisfied myself of the correctness of my conclusions, and I will, therefore, give a sketch of the more important points, illustrated by outlines from the finished drawings which may not be published for some time. As the paper is simply an abstract, all general questions, disputed points and comparisons with the results of other observers will be omitted. The drawings which are copied are from the eggs and young of two of our common Prosobranchs, Astyris lunata and Urosalpinx cinereus. Figures 5, 6, 7 and 8 are early stages in the development of Astyris, and all the others are the eggs and embryos of Urosalpinx.

The eggs of Urosalpinx are contained in small transparent membranous parchment-like vases, each of which is attached by an expanded foot to some solid substance, usually the under surface of an overhanging rock, a little above low tide mark. Each female deposits great numbers of these vases, from ten or twelve up to more than a hundred, and the process of laying occupies several weeks. When the animal is not disturbed during oviposition the vases are all attached, in more or less regular rows, to the same surface, and in this way an area of three or four square inches may be covered.

In shape and size they are much like the well known egg cases of Purpura lapillus, but they have not their slight red tinge of color. They are flattened vertically, and their edges are marked by keel-like ridges. Owing to the length of the period of oviposition, eggs and embryos in all stages of development are to be found in the various vases of a group, and the young escape from the first-laid vases before the

female has finished laying. Unlike the vases of Purpura, each of which contains several hundred eggs, those of Urosalpinx contain only from six to twenty, ten or twelve being the usual number. All of these normally undergo development and give rise to embryos, although abnormal or retarded eggs are frequently found, and the rate of development varies greatly among the eggs in the same vase. Occasionally a partially segmented egg or a more advanced embryo becomes abortive and breaks up into separate cells, each of which remains alive for some time and often swims actively by the motion of its cilia. These "cosmellae" and the yolk of the aborted eggs are drawn into the digestive cavities of other embryos; but while this method of furnishing the young with food appears to be normal with Purpura, it is accidental and exceptional with Urosalpinx. The eggs are suspended in a tenacious transparent albuminous substance which at first fills the vase, but is used up as food by the growing embryo, which increases in size many hundred-fold before it leaves the capsule.

Before segmentation the eggs are nearly spherical, opaque, yellowish white, and are made up of a ground substance or network of transparent, very slightly granular protoplasm, the meshes of which are filled with highly refractive globules of deutoplasm or food material, which are packed into the protoplasm like the starch grains in a potato. The protoplasm stains readily with carmine or with osmic acid, and is then quite conspicuous. When an egg is torn to pieces with needles the spherules of deutoplasm fall out of the spaces, but retain their shape, while the protoplasm still exhibits the sharply defined spherical chambers which contained them.

The animals will not lay their eggs in confinement, and as the vases must be collected, taken to the laboratory and

opened before the eggs can be studied, the species is not a favorable one for studying the earliest changes, and its opacity prevents the internal changes which precede and accompany segmentation from being seen.

The first external change is the lengthening of one pole, so that the egg becomes pear-shaped. The portion thus drawn out now becomes less opaque than the remainder of the yolk, owing apparently to the absorption by the transparent protoplasm of some of the opaque food spherules, and we are now able to distinguish the formative from the nutritive pole. Two or three large spheres of segmentation now separate from the formative pole, as shown in Figure 1. As in many other mollusca, a well marked period of contraction succeeds each period of active segmentation, and the segmentation spherules are alternately sharply separated from the yolk, and then partially merged in it.

The spherules which first appear are less opaque than the food yolk, and one end of each of them, the end towards the left in Figure 1, is quite transparent.

We have then, at this early stage, one pole of the egg distinguished from the other by the presence of segmentation spherules; and one side of these spherules distinguished from the other by its transparency.

Since the subsequent history shows that the final mouth of the animal is formed at the nutritive pole of the egg, and that the opaque portions of the spherules are upon what is to become the dorsal surface, we may hereafter use the terms oral and aboral, dorsal and ventral. In Figure 1 the oral end is above, the aboral below, the dorsal surface to the right, and the ventral to the left. At the stage shown in Figure 1, a transparent area is visible on the ventral side of the oral end of the food yolk, *B*. It is probable, from Brobetsky's

observations upon Nassa, that this is to be regarded as the point where a spherule, similar to those shown at *D*, has become fused with the food yolk. As the cells of the ectoderm are to be derived in great part from this transparent area, it may be called the *ectodermal area* of the food yolk. It stains readily with carmine or osmic acid, as do the transparent ends *D''* of the spherules *D*. A group of small transparent segmentation spherules now makes its appearance at the oral end of the egg and ventral to the large spherules, and soon forms a distinct layer of ciliated cells: *the ectoderm*. This layer seems to be derived in part from the transparent ventral surfaces of the primary spherules or macromeres, but mainly from the transparent ectodermal area of the food yolk.

The macromeres *D* now divide and give rise to a number of opaque spherules, much larger than the ectoderm cells, and so arranged as to form a rim around the sides and dorsal edge of the ectoderm. As these opaque large spherules give rise to the wall of the digestive cavity, we shall call them the endoderm hereafter. Figure 2 is a ventral view, Figure 3 a dorsal view, and Figure 4 a dorso-ventral optical section of the oral portion of an egg at this stage, much more highly magnified than Figure 1. In Figure 2 the ectoderm is shown at *F* as a layer of small ciliated cells, bounded dorsally and at the sides by the endoderm spherules *D*, and ventrally by the food yolk *B*. The ventral margin *F'* of this layer now extends downwards onto the ventral surface of the food yolk, by the addition of new cells to the ventral margin *F'*. These new cells appear to be derived from the ectodermal area 1. The endoderm spherules *D* are seen at the sides of the layer of ectoderm, separating it from the food yolk, and also projecting above its dorsal edge. In

the dorsal view, Figure 3, a small portion of the ectoderm *F* is seen above these spherules *D*. In the optical section, Figure 4, the ectoderm forms a single layer, *F*, of nucleated ciliated cells, which arch over a segmentation cavity *F''*. The letter *F'* indicates the ventral growing edge of the ectoderm, and 1 the ectodermal area. A comparison of Figures 2, 3 and 4 shows that the segmentation cavity is bounded below by the surface of the food yolk *B*; dorsally and at the sides by the macromeres *D* of the endoderm, and ventrally and orally by the ectoderm *F*. The latter now grows down onto the food yolk on all sides, and covers up the endoderm spherules and at the same time pushes them down towards the aboral pole. Figure 9 is the oral end of an egg at a somewhat later stage, in which the ectoderm forms a cap upon the oral end of the food yolk *B* and nearly covers the endoderm *D*. At this stage the embryo begins to rotate slowly by the action of the cilia of the cap of ectoderm. Figure 5 is a dorsal view of the entire embryo of Astyris lunata at a somewhat later stage. The food yolk *B* is now nearly covered by the cap of ectoderm *F*, which also entirely covers the endoderm *D*. The foot is now present as a fold of ectoderm upon the oral ventral edge of the embryo, and its corners are seen at *G*, projecting beyond the general outline of the oral surface.

The endoderm spherules *D* have not yet undergone very much change; they are covered by the ectoderm and are pushed down from their original position onto the sides of the food yolk, around the sides and dorsal surface of which they form an incomplete ring, open on the ventral surface, as seen in the side view, Figure 6. On the sides this belt is only one cell wide, but upon the dorsal median line it has begun to grow upwards towards the oral end of the embryo.

The embryo shown in Figure 6 is also an Astyris, a little younger than that shown in Figure 5, and seen from the left side, or in the same position as Figures 1 and 4. Both figures are from embryos which had been placed for half an hour in one-fifth per cent. solution of perosmic acid, and had then been stained with carmine. The endoderm is so obscured by its covering of ectoderm that it cannot be satisfactorily studied in a living specimen, but it is quite distinct in stained specimens.

In this figure the projecting foot *G* is quite prominent, and as it is the first organ to appear and is present in both Astyris and Urosalpinx before the closure of the blastoderm around the food yolk is completed, as well as at all later stages, it is of the greatest importance in determining the relation of organs of later formation to the poles of the segmenting egg.

At *F'* on the ventral surface, under the foot, is the opening in the belt of endoderm, and over it the growing edge of the ectoderm. Figure 7 is a median vertical optical section of Figure 5, and Figure 8 a similar section of Figure 6. As the letters of reference are the same as in the previous figures, they will at once be understood from the previous description.

As development progresses, the sides and ventral margin of the ectoderm continue to extend down onto the food yolk, and at last surround it, meeting at a point which corresponds in position to the point *C* of Figures 5 and 6, which in its relation to the endoderm is the same as the point *C* of Figures 3 and 4. Meanwhile the oral half of the food yolk becomes absorbed, and the layer of endoderm grows upwards upon the sides and dorsal surface of the embryo and thus builds up a wall or parapet around three sides of the now

nearly hemispherical food yolk, and this growth goes on until the upper margins of the walls meet at the oral end of the embryo. In this way the cavity which is left after the absorption of the food yolk becomes arched over by a roof of endoderm concentric with the layer of ectoderm, but separated from it by the segmentation cavity.

The primitive digestive cavity which is thus formed is open along the ventral median line, and it is bounded below by the oral surface of the food yolk and dorsally and laterally by the endoderm. It opens externally by a "gastrula mouth," the position and mode of formation of which will be understood by a comparison of Figures 10 and 11.

Figure 11 is a median optical section of a Urosalpinx embryo, after the ectoderm *F* has surrounded the food yolk *B* and the oral half of the latter has been absorbed. The oral end is uppermost, and the ventral surface to the left, and it is therefore in the same position as Figures 1, 4, 6 and 8. The layer of ectoderm has passed around the aboral surface of the food yolk and up its dorsal surface as far as the point *C* near the centre of the dorsal surface. A comparison with the previous figures shows that the point *C*, which in Figure 11 is the only portion of the body which is not covered with ectoderm, is the same as the point in Figure 1 where the dorsal surfaces of the segmentation spheres join the food yolk. A view of the dorsal surface of the same embryo, Figure 10, shows that the area *C* is circular and that its margin is formed by a ring of ectoderm cells, and deeper focusing shows that the oral margin and sides of this ring are in contact with the endoderm spherules *D* and its aboral margin in contact with the upper edge of the food yolk *B*. It thus forms a circular aperture, the gastrula mouth, through which the digestive cavity opens externally; it is functionally

a mouth, and food passes through it into the digestive cavity before the formation of the definitive mouth. At this stage, Figure 11, the ectoderm of the oral end of the body has become differentiated into the foot *G*, the head vesicle *K* and the invagination *I*, which is to become the definitive mouth.

This invagination does not at first reach the surface of the endoderm, and its inner end is closed. Since it makes its appearance above the foot *G*, we are able to say that it is formed at the point which is indicated by the letter *A* in Figure 6, or at one end of the long axis of the embryo. Since the food yolk is not entirely covered by the blastoderm at this stage, (Figure 6,) it is plain that the mouth invagination is formed at that pole of the egg where segmentation commences, and which we have called the oral pole.

At the stage shown in Figures 10 and 11, the endoderm *E'* has grown upwards dorsally and at the sides, and the digestive cavity *E''* is nearly shut in, although there is still an uninclosed belt or zone along the ventral median line, represented by dotted lines in Figure 11. The greater part of the wall of the digestive cavity is so filled with small vacuoles that the outlines of the constituent cells could not be traced; but along the dorsal and lateral edges, where it meets the food yolk, the large endoderm spherules *D* can still be seen. In the dorsal view of the same embryo, Figure 10, the primative urinary organs *H* are seen at the sides of the body, covered with a single layer of small nucleated polygonal cells and filled with a loose mass of nearly spherical cells, the origin of which was not traced.

At a later stage of development, the endoderm meets along the ventral median line, and the oral end of the embryo is then composed of two nearly concentric layers of cells, the

ectoderm and endoderm, separated by a body cavity, which appears to be identical with the cavity of segmentation. For some time the floor of the digestive cavity is the surface of the food yolk *B*, but in time the endoderm grows inwards, as shown by the dotted lines at *E'* in Figures 10, 11 and 12, and separates the food yolk from the cavity. Before this floor is completed, the albumen of the egg capsule is drawn into the digestive cavity, through the gastrula mouth, apparently by ciliary action. The cavity becomes greatly distended and the long axis of the embryo lengthened, as shown in Figure 12.

The ectoderm is stretched by this inflation, and the foot *G*, Figure 12, and the mouth invagination *I* are thus rendered less conspicuous than at an earlier stage. The endoderm, on the contrary, absorbs nutriment from the food, thickens, and becomes filled with great numbers of oil-like vacuoles, and is more conspicuous than at an earlier stage.

Along the dorsal portion these vacuoles unite and form one large one for each cell, and the outlines of the separate cells become visible. The velum *L* makes its appearance as a band of large nucleated cells, with long cilia, and running across the anterior end of the body, dorsal to the mouth invagination. At *H* one of the primitive kidneys is shown, and it will be seen that it is much nearer the anterior end of the body than in Figure 10. At this stage the floor *E'* of the digestive tract is not quite completed, and near the dorsal surface a small portion of the food yolk is still exposed. The margins of the gastrula mouth are now greatly thickened, and before the floor of the digestive tract is quite completed, the opening is obliterated and its margins become the shell gland, Figure 12, *C*, upon which a small circular transparent shell, *M*, soon appears. The closure of the gastrula mouth and formation

of the shell take place before the invagination *I* of the true mouth unites with the endoderm.

Figure 13 is a somewhat older embryo, less highly magnified than Figure 12, but in nearly the same position. The marked change in the general form and outline of the body is the result of a ventral flexure of the long axis. The dorsal surface is thus lengthened, the ventral shortened, and the oral and aboral poles brought nearer each other.

The ectoderm is now continuous over the spot *C*, where the gastrula mouth was situated at an earlier stage, and the shell, which has now increased greatly in size, has moved from its primative position over the point *C* and is now a symmetrical circular cap, *M*, upon the convex dorsal surface of the bend in the body of the embryo. Around its edge is a thickened ridge, *R'*, the rudimentary mantle.

The food yolk *B* is of about the same size as in Figures 10, 11 and 12, but it is now entirely shut off from the digestive cavity *E''* and lies between the integument *F* and the endoderm *E'*.

The mouth invagination now communicates by a short ciliated œsophagus, *I*, with the digestive tract, and the embryo draws into its stomach the yolk of abortive eggs and fragments of other embryos, as well as the transparent albumen. As the solid particles are drawn through the œsophagus, they are pressed and twisted into long strings, *N*, which are frequently to be found in the digestive cavity. The foot *G* is now quite conspicuous, and the velum *L* begins to bend towards the dorsal surface. The embryo now grows very rapidly, and at the stage shown in Figure 14, is three or four times as large as that of Figure 13, and is represented in substantially the same position. Up to this time the embryo has been bilaterally symmetrical, but the symmetry

is now departed from by the twisting of the aboral pole towards the right side. In a side view, as in Figure 14, the outline is roughly triangular; one angle being formed by the head vesicle *K*, another by the food yolk *B*, and the third by the bend in the dorsal surface which is covered by the shell *M*; the dorsal surface forms two of the sides of the triangle, and the third, more broken side is formed by the outlines of both the ventral surface and the oral end of the embryo. Owing to the twist which is mentioned above, the front view of the embryo is no longer symmetrical. At the earlier stage shown in Figure 13, a view from in front, or along the line *EB*, would be perfectly symmetrical, and the food yolk *B* would be hidden behind the oral end of the body. In a similar view of Figure 14, that is a view along the line *KB*, the whole of the food yolk *B* would be seen to the right of the head vesicle *K* and the velum *L*, as is shown in the somewhat older stage, Figure 15. In Figure 14 the shell *M* is still nearly symmetrical, and still rests like a cap upon the rounded angle formed by the flexure of the dorsal surface. The organs at the oral end of the body are now quite highly developed. The foot *G* is a large projection which contains a cavity, which is traversed in various directions by a network of contractile cells, with the central nucleated body and radiating processes so characteristic of the interstitial connective tissue corpuscles of the mollusca. Among them a few free white blood corpuscles may occasionally be seen; and as the foot changes its shape, through the contraction of the radiating processes, the blood corpuscles are driven from one point to another. The head vesicle *K* is similar to the foot in structure, but its cavity is larger, its contractions more regular, and its functions as an embryonic heart much more efficacious. No trace of a dis-

tinct layer of mesoderm, such as is readily recognized in this region of a fresh water pulmonate at this stage, could be detected. The velum *L* is now well developed, and its free ends nearly meet upon the dorsal surface of the neck. In a view from in front the halves of the velum are seen to project from the sides of the body, as in those Gasteropods where the veliger embryo leads an active life. The œsophagus is now a long cylindrical ciliated tube, slightly bent upon itself, so that the convex side of the bend is dorsal. The digestive tract is still a large unspecialized chamber, which fills nearly the whole embryo. During growth the endoderm cells continue to grow more conspicuous, and they also increase greatly in size, and are represented in Figure 14 about as large as in Figure 12, although the latter embryo is much smaller and more highly magnified.

The endoderm and ectoderm are in contact over the greater portion of the surface, except posteriorly, where they are separated by the food yolk *B*, and at the oral end of the body. At the point *O* a ciliated depression indicates the point where the anus is to be formed, and a thickening of the ectoderm, not shown in any of the figures, runs inwards to form the rectum. This is at first a solid cord, and it becomes hollow and communicates with the digestive tract at a later stage. I was not able to determine how much of the intestine is formed from this plug of ectoderm.

By a comparison with the previous figures, the point *O* will be seen to be separated by the width of the food yolk from the point where the gastrula mouth was situated.

The subsequent changes of the now rapidly developing embryo are too complicated to be described without carefully finished drawings, but outlines are given of four of the most characteristic of my figures of the later stages.

Figure 15 is an embryo older and much larger and less highly magnified than Figure 14, and viewed from in front or along the line *KB*; in Figure 14 and Figure 16 a still older and larger embryo is shown from behind. The two folds of the velum, *LL*, now project considerably from the sides of the neck, and the relation of this organ to the head vesicle and foot will be best understood by a comparison of Figures 14, 15 and 16. In Figure 14 the head vesicle *K* is dorsal to the mouth, and in Figure 15 it is a nearly spherical chamber, *K*, in front of the velum *L*. In Figure 16 part of its outline, *K*, is seen in front of the velum. In Figure 15 the œsophagus *I'* and the buccal cavity *I* are seen through the head vesicle, and beyond them is the foot *G* and the outline of the neck. The primitive kidneys have now passed forward and project from the sides of the neck at *H*, in Figures 14, 15 and 16. In Figure 16 the foot *G* is a large creeping surface, anterior to which is the mouth opening *I*; at the point where the head vesicle joins the velum, the tentacles *V* have now made their appearance. In both figures the food yolk *D* is seen a little above the velum and upon the right side of the embryo. It is a little difficult to use the terms right and left in the description of an irregularly twisted form, but it will be seen that if either of these figures were rotated until the creeping surface of the foot were below, and the head vesicle anterior, the food yolk would be on the right side. In Figure 15 the shell is still nearly symmetrical, although it has increased greatly in size and now covers all of the body, except the portions which formed the two ends of the embryo in Figure 10. The endoderm cells have increased greatly in size, and are of the same apparent size as in the more magnified figures of earlier stages. Around the margin of the shell there is, as in earlier stages, a thickened

rim, the mouth, and anterior to this, on the right side of the dorsal surface of the neck, the integument becomes folded at *S* to form the mantle chamber. The edges of this chamber are slightly scolloped, and the projecting points are the beginnings of the gill filaments. Within this cavity a large rythmically pulsating organ, *T*, the embryonic heart, now makes its appearance. The shell now becomes asymmetrical, the right side of the dorsal margin, that is the margin nearest the mantle cavity *S*, growing most rapidly; and the shell soon assumes a spiral form, as shown in Figure 16. A comparison of this with the preceding figure shows that the lip of the shell of the adult is the right margin and the columella the left margin of the embryonic cup-shaped shell. In the stage shown in Figure 16, the margin of the columella is bent outwards at *U*, thus forming a fold, which lies upon the posterior face of the body, or neck, just above the foot. This latter organ is at this stage placed at right angles to the long axis of the aperture of the shell, but it soon rotates so as to be parallel to this axis, as shown in Figure 18; at the same time it increases in size and becomes about as long as the shell. By this rotation and growth the upper surface of the foot is brought into contact with the columellar flap *U*, which grows and becomes the operculum. For some time this is united to the shell by an elastic hinge or line of flexure. When the foot is withdrawn into the shell, the operculum bends down with it into the aperture, bending along the line where it is reflected outwards from the columella, but it soon becomes separated from the shell, and the growth of the foot carries it away from the columella, as shown in Figure 18. The velum begins to become rudimentary at about the stage shown in Figure 16, and at the stage shown in Figure 17 it is quite small, and in Figure 18, the

stage in which the animal escapes from the capsule, it has disappeared.

The large food yolk and the supply of food contained in the vase are sufficient to carry the young animal up to the true gasteropod form, and the free-swimming veliger stage of development is omitted, although the tendency to develop a velum is still retained.

The changes which we have described may now be briefly recapitulated, as follows:

Segmentation takes place at one pole, the oral pole, of the large yolk and results in the formation of a blastoderm.

Two kinds of segmentation spherules are distinguishable at a very early stage: large opaque spherules, which ultimately give rise to the wall of the greater part of the digestive tract, and much smaller transparent spherules, which soon become ciliated and form a layer ventral to the endoderm and arching over the segmentation cavity. The endoderm spherules become arranged in a band around the sides and dorsal margin of the food yolk, and the layer of ectoderm extends over them and also down onto the ventral surface of the food yolk. The endoderm is also pushed down onto the sides of the food yolk with the growth of the ectoderm.

The foot now makes its appearance at the oral ventral end of the embryo.

The ectoderm surrounds the food yolk, and form the margins of the gastrula mouth, upon the dorsal surface.

While the digestive cavity still opens externally by the gastrula mouth, the true mouth invagination makes its appearance at that end of the embryo where the segmentation began. The digestive cavity is formed by the absorption of the oral half of the food yolk, and the walls of the cavity are derived from the macromeres. For some time the aboral floor

of the digestive tract is formed by the surface of the food yolk, but the edges of the endodermal wall soon become reflected inwards and at last form a continous floor which separates the food yolk from the digestive cavity. Before this floor is completed, or the true mouth communicates with the cavity, the margins of the gastrula mouth become thickened to form the shell gland, and the opening disappears. Soon afterwards the true mouth is formed, and later the anus and intestine, and a considerable portion of the latter is derived from the ectoderm.

At first the body is long, cylindrical and bilaterally symmetrical, and the mouth is at one end and the shell upon the dorsal surface, but it soon bends upon itself so as to shorten the ventral surface and bring the extremities nearer each other, and a second twist carries the aboral end of the body onto the right side, and the most posterior portion of the body is now the middle of the dorsal surface.

A velum is now developed, but soon lost, and the animal leaves the egg case as a true Gasteropod.

The developmental history here traced is of especial interest in its relation to the gastrula theory. The typical gastrula stage, resulting from total regular segmentation, as in the Echinoderms and Paludina or Cyclas, is an elongated double walled vase, with an opening at one end, and an axially elongated cavity.

The outer wall of transparent ectoderm is not differentiated into organs, and it unites with the endoderm, which is also undifferentiated, around the margins of the aperture.

It is clear that no stage in the present development is a typical gastrula stage, nor is there any stage which can be regarded as a specialized gastrula stage complicated by the formation of other organs; but a little study will show that

the embryo presents at different periods all the phases in the formation of a gastrula, although there is no time when all the characteristics of a gastrula exist together. The gastrula *stage* has disappeared, but the gastrula *form* persists, and may be recognized by neglecting all those complications of structure which do not take part in its formation. Suppose, for instance, that the differentiation of the ectoderm of the oral end of the body, which in Figure 10 indicate the positions of the foot, mouth, velum and head vesicles, did not make their appearance until a later period, we should then have at this stage an undifferentiated layer of ectoderm, entirely surrounding the embryo, except at the point *C*. At the same time, imagine the development of the wall of the digestive tract accelerated, and the cavity entirely separated from the food yolk, before the specialization of the gastrula mouth as a shell gland.

We should then have a central digestive cavity, surrounded by two layers of cells, widely separated on one side by the food yolk.

If this were away, the embryo would then be a typical radically symmetrical gastrula. If the food yolk were wanting, the development of the wall of the digestive tract accelerated, the development of the foot, mouth invagination, velum and head vesicle retarded, we should have a true gastrula; or, conversely, the acccleration of the development of the latter organs, and the retardation of that of the digestive cavity, and the presence of a food yolk, might so modify a typical gastrula, as to give us the form of development which we here find.

DESCRIPTION OF THE PLATE.

All the figures are from the embryos of Urosalpinx cinereus, excepting Figs. 6, 7, 8 and 9, which represent an early stage in the development of Astyris lunata.

The letters of reference are the same for all the figures, and are as follows:

A. The *Germinative* or *Oral Pole* of the embryo.

B. The unsegmented *Food Yolk* at the *Nutritive Pole* of the embryo.

C. The point upon the dorsal surface of the embryo, where the *gastrula mouth* is situated during the stage of development shown in Fig. 11. At the stage shown in Fig. 12, the *shell-gland* occupies the area where the gastrula mouth was situated a little earlier.

D. The large opaque segmentation-spheres, which form the *Endoderm.*

D'. In Fig. 1, the more opaque dorsal endodermal portion.

D''. In Fig. 1, the transparent ventral ectodermal portion.

E. The endodermal wall of the digestive cavity.

E'. The portion of this wall which is reflected onto the oral surface of the food yolk.

E''. The cavity of the embryonic stomach.

F. The *Ectoderm.*

F'. That margin of the layer of ectoderm which grows down onto and around the food yolk.

F''. The *Segmentative* Cavity.

G. The *Foot.*

H. The *Primitive Renal* Organ.

I. The *Definitive* Mouth.

K. The *Head Vesicle.*

L. The *Velum.*

M. The *Shell.*

N. A mass of food which has been drawn through the mouth into the digestive cavity.

O. The *Anus.*

R'. The Mouth.

S. The mantle cavity.
T. The embryonic heart.
U. The operculum.
V. The tentacles.

FIGURE 1.—An egg, at a very early stage of segmentation, seen from the left side and magnified 100 diameters.

The egg is considerably lengthened along the axis which passes through the area of segmentation. Two segmentation spherules are sharply defined and project from the dorsal side of the oral end of the food yolk. Each of these is divided into a dorsal opaque granular portion, which is to give rise to the spherules of the endoderm, and a more transparent ventral portion from which the ectoderm is to be, in part, derived. A third segmentation spherule has become fused with the food yolk, ventrally to the two projecting spherules, and is destined to give rise to the greater part of the ectoderm.

FIGURE 2.—The germinative pole of an egg, at a later stage of development, viewed from the ventral side and magnified 250 diameters.

The food yolk, only a small part of which is shown in the figure, has regained its nearly spherical shape, and on its surface, just below the ventral edge of the layer of ectoderm, is seen the sharply defined transparent area which gives rise to new ectoderm spherules. Behind the layer of ectoderm *F*, the upper edges of the larger endoderm spherules are seen, and the smaller endoderm spherules *D*, *D*, extend around onto the sides of the area of ectoderm.

FIGURE 3.—The same egg, viewed from the dorsal surface.

The layer of ciliated ectoderm is now seen at *F*, projecting beyond the endoderm spherules *D*, *D*.

FIGURE 4.—Optical section of the same egg. Its dorsal side is towards the right.

By the addition of new spherules, derived from the food yolk, at *F'*, the ventral edge of the layer of ectoderm gradually extends down onto the food yolk, while its dorsal margin extends towards *C*, over the endoderm *D*, by the addition of spherules derived from the latter.

FIGURE 9.—This figure should come next in order, but, by an oversight, it has been incorrectly numbered. It is a ventral view of the oral pole of an egg at a later stage than Figure 2.

The layer of ectoderm *F* has spread over the endoderm spherules *D*, and begins to push them down onto the sides of the food yolk.

FIGURE 5.—The embryo of Astyris lunata, viewed from the dorsal surface, at a later stage than Figure 9.

The layer of ectoderm has spread over the food yolk *B*, so as to nearly cover it. It has also covered the endoderm spherules *D* and pushed them down onto the sides of the food yolk.

FIGURE 6.—The same embryo, seen from the left side.

FIGURE 7.—Optical section of Figure 5.

FIGURE 8.—Optical section of Figure 6.

FIGURE 10.—Dorsal view of a still older embryo of Urosalpinx.

The ectoderm now entirely surrounds the food yolk, except at the point *C*, the gastrula mouth. The primitive kidneys *H* project from the sides of the body.

FIGURE 11.—Longitudinal section of the same embryo, in the same position as Figures 4, 6 and 8.

The head vesicle *K*, the mouth invagination *I*, and the foot *G*, have now appeared at the end opposite the food yolk *B*.

FIGURE 12.—An older embryo in the same position, showing, in addition to other features, the velum *L*, the shell gland *C*, and the shell *M*.

FIGURE 13.—Similar view of an older embryo, magnified only 150 diameters.

The gastrula mouth has disappeared, the true mouth *I* has been formed, and the digestive cavity *E''* contains strings of food *N* which have been drawn into it through the short œsophagus.

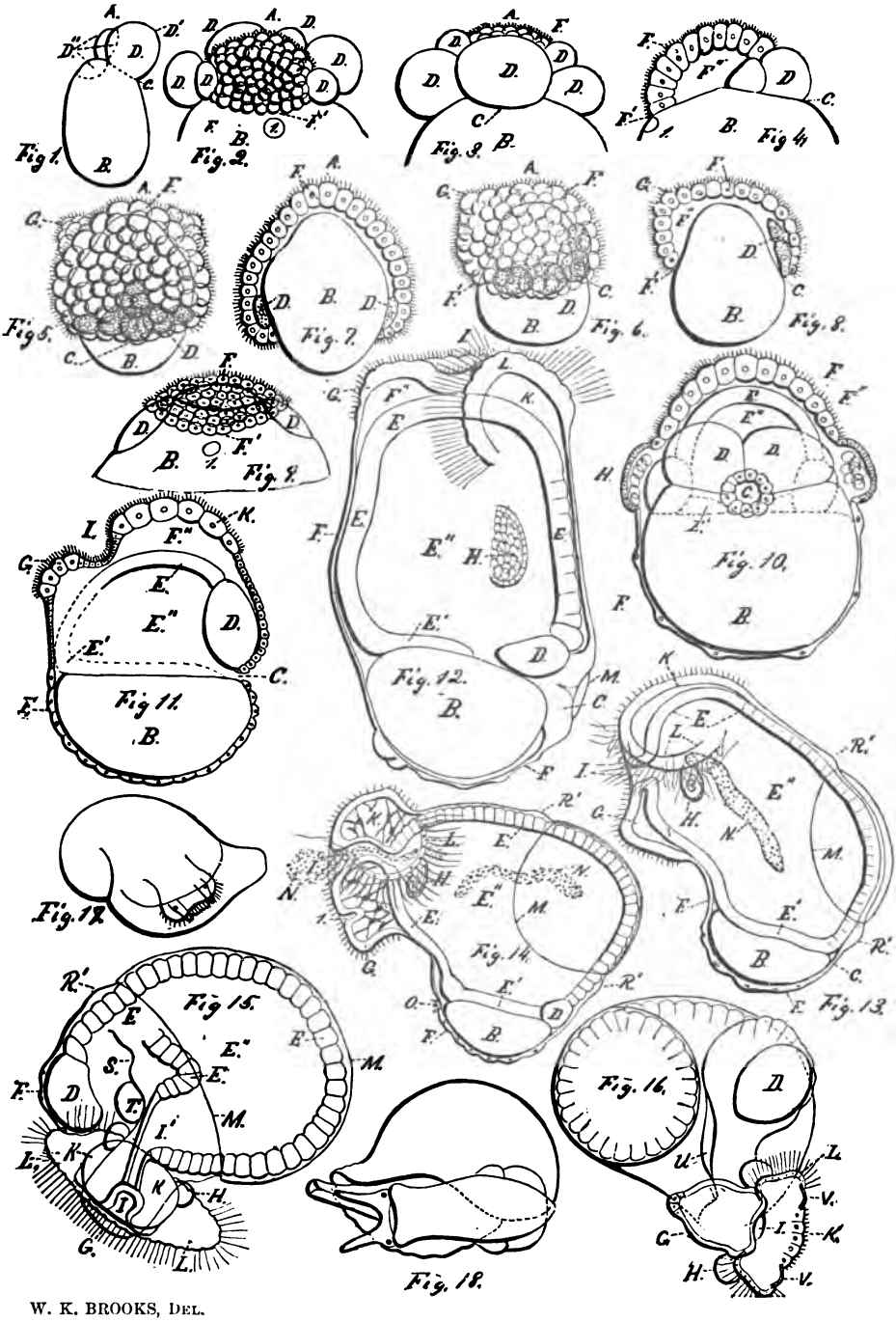
FIGURE 14.—A nearly similar view of a still older embryo, magnified 100 diameters.

FIGURE 15.—The anterior aspect of an older embryo.

FIGURE 16.—Still older embryo, viewed from below, magnified 75 diameters.

FIGURE 17.—The young gasteropod retracted within its shell.

FIGURE 18.—An older one, expanded, and seen from below. This represents the stage at which the young usually leave the capsule.



W. K. BROOKS, DEL.

The Larval Stages of Squilla Empusa. Say.

By W. K. Brooks.

Squilla empusa, the only described Stomatopod found upon our coast, was described under the above name by Say, (Journal Acad. Nat. Sci., Philadelphia, vol. I, p. 224, 1818,) and again described, under the same name, and figured by Dekay, (Nat. Hist. of New York, 1844, p. 32, Pl. 13, Fig. 54,) and again described, under the same name, by Gibbs, (Proc. Amer. Assn., 3d meeting, p. 199.) According to Milne Edwards, (Hist. Nat. des Crust.,) the points of difference from Squilla mantis are very slight, but they are sufficient, according to the above writers, to make it a distinct species. It is met with occasionally on sandy bottoms from Cape Cod to Florida, and its free-swimming larvae are occasionally captured at the surface at Wood's Hole, Newport, and other points along the New England coast, but it is not usually found in abundance.

At Fort Wool the young were frequently met with by hundreds, and an evening's collecting always yielded several specimens. The adults

appear to be quite numerous in the Chesapeake Bay, and I am told by Mr. Jesse Price, that it is often captured in abundance upon the sand beaches near Old Point Comfort, in the fall, and he tells me that it is known to the fishermen as the sand shrimp and is eaten. The average length is from two to four inches, but much larger individuals are frequently found.

In his report upon the "Invertebrate Animals of Vineyard Sound," (U. S. Fish Commission Rep. 1871 and 1872, p. 369,) Verrill gives the following account of the structure and habits of the adult:

"The Squilla empusa is a very interesting creature, whose habits are still imperfectly known. It is often thrown on the beaches by the waves, and probably it usually burrows in the mud, below low-tide mark, but in certain localites it has been found burrowing at or near low-water mark of spring tides, forming large, irregular holes. . . . . Large specimens are eight or ten inches long, and about two broad."

(Plates 4 and 5 of the present paper give a dorsal and a ventral view of the animal and are of about the same size as a moderately large specimen.)

"The body is not so stout built as that of the lobster, and the carapax or shell is much smaller and softer, while the abdomen is much larger and longer in proportion. The legs and all the other organs are quite unlike those of the lobster, and the last joint of the great claw, instead of forming a pair of pincers with the next, is armed with a row of six sharp-curved spines, which shut into corresponding sockets, arranged in a groove in the next joint, which also bears smaller spines. By means of this singular organ they can hold their prey securely, and give a severe wound to the human hand if handled incautiously. It also uses the stout caudal appendages, which are armed with spines, very effectively. The colors of this species are quite vivid, considering its mud-dwelling habits. The body is usually pale green, or yellowish green, each segment bordered

posteriorly with dark green and edged with bright yellow; the tail is tinged with rose, and mottled with yellow, and blackish; the caudal lamellae have the base and spines white, the last joint yellow, margined with black; the inner ones are black pale at base; the eyes are bright emerald green; the inner antennae are dark, with a yellow band at the base of each joint; and the flagellum is annulated with black and white."

The group Stomatopoda, of which Squilla is a representative, is quite small and sharply defined, and while its representatives are very much like the Decapods in most respects, they differ not only from them, but from all other Crustacea, in certain characteristics, such as the possession of a long tubular insect-like heart, and in having the eyes and antennae carried upon distinct, movable body segments.

Their adult structure is of the greatest morphological interest, and a knowledge of their development is of especial importance, as we are here presented with what may be regarded as the simplest expression of the highly complicated metamorphosis of the higher Crustacea. Whether the view advocated by Claus, (Genealogischen Grundlage des Crustaceen-Systems,) as to the origin and significance of the zoea stage, be or be not correct, it is nevertheless true that the Squilloid zoea bears a more intimate relation to the adult than is the case with other stalk-eyed Crustacea, and the development of Squilla is therefore an excellent basis for comparative work in this department.

The station at Fort Wool presents unrivalled facilities for the study of Crustacean development, and I hope that these opportunities will in future seasons be utilized for the advancement of our comparative knowledge of the subject. Although my observations upon Squilla were not as exhaustive as another season's work might have rendered them, it seemed best to have them published as a basis for such future comparative work, and I have therefore selected them for publication from among the notes on Crustacea made during the summer.

While the literature upon the development of this highly interesting group is very scanty, it is sufficient to show that the adults of the various genera and species are much more alike than their larvae. This reversal of the general morphological law that allied animals become more different from each other as they pass from the egg to the adult form, is not unusual among the Crustacea. The larvae of a number of Stomatopods have been described as adults under the generic names, Alima, Erichthus, Squillerichthus and Erichthoidina, but the first description of a Squilloid larva, as such, is by Fritz Müller, (Bruchstück zur Entwickelungsgeschichte der Maulfüsser, Arch. f. Naturgeschichte, XXVIII, 1862, p. 353, and XXIX, 1863, p. 1.)

He figures two larvae, XXIX, Taf. I, Fig. 1, and XXVIII, Taf. XIII, Fig. 1, which are very

different from each other in form, and in the number of segments and appendages. He thinks it probable that the one figured in the first paper is derived from that figured in the second, and that they are successive stages in the development of one species.

The smallest larva, described in the second paper, is an "Erichthoidina." The transparent body is divided into three regions of nearly equal length: the anterior region is unsegmented; carries a pair of large sessil compound eyes; a median ocellus; two pairs of short jointed unbranched antennae, and the mouth parts. The second region of the body is made up of five segments, each of which carries a pair of long two-branched swimming feet. The first and second regions are covered by a large carapace, with a median frontal, and two posterior lateral spines. The third region is made up of three segments without appendages, and a large terminal plate or telson.

The second larva, an "Alima," is similar in all essential points to that shown in Plate 9, Figure 3, of the present paper. As he was unable to trace the metamorphoses of the first form into the second, or of either into the adult, his view that they belong to the same series is only a conjecture, and, according to Claus, an erroneous one. This observer, (Die Metamorphose der Squilliden,

von Prof Dr. C. Claus, Nachrichten von der königl. Gesellsch. zu Göttingen, 1871, 6, p. 169,) was led by the examination of a large collection of preserved material, to the view that there are two quite distinct forms of development among the Stomatopods.

He found a number of larvae in the same stage of development as that figured in Müller's second paper. These larvae were alike in all essential features, but could be separated, by differences of outline, into four sets, each of which probably represented a distinct species. With each of these forms a larger and more advanced larva, with the same specific characteristics, but in the "Erichthus" stage, was found associated, and Claus accordingly infers that the "Erichthoidina" develops into an Erichthus. Associated with one of these four forms he found a still more advanced larva, with the same specific characteristics, but in the form of the old genus Squillerichthus, and this again was joined onto a young Squilloid, with the characteristics of the adult genus Gonodactylus.

Claus accordingly concludes that Müller's Erichthoidina is the youngest post-ovan stage in the development of the genus Gonodactylus, and that the adult form is reached in this genus by a very complex metamorphosis, during which the animal passes through stages which had previously been regarded as adults, and had

been described under the generic names Erichthus and Squillerichthus.

Claus also found the "Alima" larva, which is figured in Müller's first paper, associated with a similar, but more advanced Squilloid larva, the larger and older specimens of which exhibited the characteristics of the adult of the genus Squilla, and he infers that "Alima" is the young of Squilla, which accordingly passes through a metamorphosis, which is very much more direct than that of Gonodactylus.

From some unpublished observations by Faxon, which I have had the opportunity to examine, I am led to believe that these two forms of development are not the only ones which will be found to occur among the Stomatopods, and that this very complicated department of embryology demands careful observation of the actual metamorphosis of the larva, in as many species as possible; a work which can be carried on no where but at a sea-side laboratory. My observations, however, tend to substantiate the second part of Claus' conclusion; that the Alima form is the young of the genus Squilla, and that it is transformed into the adult by a pretty direct metamorphosis.

Claus' paper, above referred to, is not illustrated; but he published a year after a second paper, to which I have not been able to refer,

(Die Metamorphose der Squilliden. Abhandlungen der königl. Gesellschaft der Wissenschaften zu Göttingen, 1871,) which I believe is illustrated. In his "Untersuchungen zur Erforschung der Genealogischen Grundlage des Crustaceen-Systems, 1876," he gives a short abstract of this paper, pp. 3 and 4, illustrated by three figures, p. 4, Figures 4, 5 and 6, of the second or simple form of development. The larvae figured are specifically distinct from those described in the present paper, but they are substantially the same; and the more complete series which I have have had the opportunity to study, as well as the fact that I have found an earlier stage than the youngest one described by Claus, render it pretty certain that the Erichthoidina stage is lacking in the genus Squilla, and that the individuals of the genus leave the egg as an Alima, which is developed into the adult form without any great metamorphosis. The only other published account of Squilloid larvae, with which I am acquainted, is by S. J. Smith. In his paper, on "The Metamorphosis of the Lobster, and other Crustacea," U. S. Fish Commission Report for 1871 and 1872, p. 536, he gives a description and a figure of a single stage in the development of Squilla empusa; a stage which is a little earlier than that shown in Plate 11, of the present paper, and between it and that shown in Plate 10.

During the past summer, Stomatopod larvae were met with at Fort Wool in the greatest abundance, two or three hundred being sometimes collected in a single evening. During the season there was a gradual increase in the size of the larvae; the smallest ones being most abundant in the early part of July, and very rarely met with in August; no large larvae were found in July, while the collections made in the first half of August consisted almost entirely of larvae in the later stages of development.

In a group where the development of closely allied forms is known to vary greatly, the only perfectly satisfactory method of investigation is by rearing a larva in confinement and watching its transformation into the adult. As I did not succeed in making the larvae thrive in confinement, I am not able to present such a series of observations upon one individual, and as our session at Fort Wool closed in the middle of August, before the larvae had entirely completed their metamorphosis, there is a bare possibility that they are not the young of Squilla empusa, but of some other Squilloid. The thousands of larvae which were collected, appeared to be specifically identical, however, and the series of forms, which were collected, was so complete, and the differences between the successive stages so slight, that there seems to be no reason to

doubt that they are all of the same species, and that species the only one which is known to occur in the Chesapeake Bay, Squilla empusa, (Say.)

The grotesque larva, Plate 10, appears, at first sight, to bear little resemblance to the full-grown animal, Plate 13, but the changes by which it is converted into the adult are very gradual, and can hardly be called a metamorphosis.

These changes are, an increase in the number of segments and appendages, and the alteration of the relative size of different parts, but each appendage has, at its first appearance, substantially the same form and relation as in the adult, and the changes of shape are very slight indeed, as compared with those of most podopthalmate Crustacea.

The youngest stage which was observed, is shown, magnified about 75 diameters, (Zeiss, Obj. A., Oc. 2,) in Figures 1 and 2, Plate 9. Great numbers of young were found in this stage, and as no younger ones were met with, this is probably the form in which they escape from the eggs, and commence their larval life. The young at this stage, the "Alima," has most of the characteristics of a Decapod zoea. The eyes, 1, the antennules, 2, the antennae, 3, the mandibles, 4, and first and second maxillae, 5 and 6, are present, and have substantially the same form as the cor-

responding appendages of the adult. The first and second maxillipeds, 7 and 8, are quite large, and the second pair project from the sides of the carapace, and have the form of the grasping arms, Plate 12, 8*, of the adult. The first and second maxillipeds differ from those of a Decapod zoea, since the exopodite is wanting, and the long jointed endopodite is not fringed with setae, and does not seem to be of much importance as an organ of locomotion.

The anterior half of the body is covered by a large zoea-like carapace, the anterior and posterior margins of which are prolonged into projecting spines. At the base of the long anterior spine, between the eye-stalks, on the ventral surface, there is a single small black ocellus, which should be shown in Figures 1 and 3 of Plate 9, just above the lower end of the line 1'.

This dot was so small in the original drawing that it has not been copied in the photo-electrotype, but it is shown in Plate 10, a little above the lower end of the line 0, and in Plate 11, Figure 1, at the end of the line 1.

The mid-body, or that organ which in the adult includes all the segments from the 9th to the 14th with their appendages, is here an elongated area without appendages, but showing, at its anterior end, a division into segments.

Following this is the flexible abdomen, terminating in a large telson, 20–21, which is preceded by five free abdominal segments, the first four of which carry swimming feet, represented only on one side of the figures.

The next stage which was figured is shown in Plate 9, Figure 3. This is a ventral view, drawn with the same magnifying power, 75 diameters, but somewhat reduced, so that the actual increase in size is greater than that shown in the figure. No larvae were found between this stage and that shown in Figure 1, and the change is probably brought about during a single moult.

In Figure 3 the mid-body is divided into its full number of six segments, 9–14, which are of about equal size, and none of them are furnished with appendages. As in the preceding stage, the abdomen consists of five segments, with appendages upon the first four, and a telson.

The next stage figured, Plate 10, was also drawn with a magnifying power of 75 diameters, but it is still more reduced than Figure 3, Plate 9. It also is a ventral view. A number of larvae were found between these two, and the interval between them represents at least two moults. The carapace and telson have undergone considerable change of form, and the occular segment, 0, has become marked off at the anterior end of the body. The appendages of the six seg-

ments of the mid-body are now visible as minute buds, 9*, 10*, 11*, 12*, 13*, 14*, projecting from the ventral surfaces of these segments.

The first and second of these segments, the ninth and tenth from the anterior end of the body, are much more narrow than the others, and their appendages point outwards. The fifth abdominal segment, 19, is now furnished with a very small pair of swimming feet, 19*, and the ganglion of the sixth abdominal segment, 20, has made its appearance, although the segment itself is not yet formed.

The next stage which was figured, Plate 11, Figure 1, was drawn with a magnifying power of about 30 diameters, and the drawing was more reduced than in Plate 10. The actual increase in size is therefore considerably more than twice that shown by the figures. Intermediate forms were collected, and several moults probably occur between the two stages figured. A figure, by Emmerton, of a stage which is probably one moult earlier than Plate 11, Figure 1, accompanies Smith's paper, already referred to, (U. S. Fish Commission Report, 1871 and 1872, Plate VIII, Fig. 36, No. 519.) In Plate 11, Figure 1, the carapace and telson have undergone considerable change of shape: the antennulary segment, 2, has separated from the anterior end of the body; the first three segments of the mid-body, 9, 10 and 11,

have become crowded together; their ganglia are in contact with those of the preceding segments, and their appendages are chelate, and begin to twist forwards between the bases of the large grasping limbs. The sixth abdominal segment, 20, has separated from the telson, 21, and carries a pair of appendages, 20*, which are larger than those of the preceding segments, and have substantially the same form as the large swimmerets of the adult, Plates 12 and 13, 20*.

Older stages than this were examined and drawn, but as the changes, which occupy several moults, are very slight and consist mainly in a gradual approximation to the shape and proportions of the adult, they have not been engraved. Soon after the stage shown in Plate 11, Figure 1, the antennary segment separates from the anterior end of the body, so that we have, as in the adult, three free segments, Plate 11, Figure 3; 1, 2, 3; and Plates 12 and 13, *o*, *p* and *q*; in front of the carapace. In the adult the 9th, 10th and 11th segments, that is, the 1st, 2d and 3d of the mid-body, are crowded together, and their chelate appendages, Plate 12, 9*, 10* and 11*, are directed forwards and lie below the mouth parts.

I will now describe the various stages of development, more in detail, and as all my notes were in the form of sketches, this description will be little more than an account of the figures.

THE CARAPACE.

In the youngest larva, Figures 1 and 2, Plate 9, the carapace, including the rostrum, covers a little more than one-half the length of the body. The rostrum, *d*, is about half as long as the body of the carapace, and a little behind the point where it joins the carapace are a pair of small spines pointing forwards and outwards, which I shall call the *antero-lateral* spines, Figure 1, *e*. The margins of the carapace in front of these spines, what may be called the *antero-lateral* margins, meet at the base of the rostrum in an acute angle. At the outer angles of the posterior margin of the carapace are a pair of large spines, *f*, about as long as the rostrum, which I shall call the *postero-lateral* spines. The margin of the carapace between the antero- and postero-lateral spines, the *lateral* margin, is symmetrically curved, so that the middle of the carapace is much wider than the ends. The posterior margin of the carapace is deeply notched on the median line, where it passes over the body, and on its upper surface there is a short *dorsal* spine, *i*, Figure 2. At this stage the posterior margin of the carapace crosses the body at a point which corresponds to the constriction between the 13th and 14th segments of an older larva.

In the second stage, Figure 3, the carapace is much longer, and with the rostrum now makes three-fifths of the length of the body; the posterior margin still lies above the constriction between the 13th and 14th segments, and the increase in length is therefore due to the growth of the anterior half of the body. The various spines are of about the same relative size as at an earlier stage, but the antero-lateral margins of the carapace now make an obtuse angle with each other at the base of the rostrum, and the lateral margins are nearly straight and parallel. The outline of the carapace is accordingly rectangular instead of oval.

In the next stage figured, Plate 10, the carapace extends backwards only to the middle of the 13th segment, but notwithstanding this, its length is greatly increased, and with the rostrum it now forms two-thirds of the length of the body. Most of this increase is in the rostrum, which is now as long as the body of the carapace, instead of only half as long. The antero- and postero-lateral spines are also much longer than at an earlier stage, and the postero-lateral spines are slightly curved, but the curvature is probably due to the pressure of the cover glass which I was compelled to use to keep this larva in a proper position for drawing. All the drawings were made from living specimens, and it was especially difficult to keep

those at this stage quiet, or on their backs. The antero-lateral margins now meet the greatly enlarged base of the rostrum at quite an obtuse angle, and the nearly straight lateral margins diverge from each other, so that the space between the bases of the postero-lateral spines is almost twice as wide as that between the antero-lateral spines.

In the next stage the posterior margin of the carapace reaches only to the middle of the 12th segment, and the outline is substantially as before; the rostrum is still about as long as the body of the carapace, but in a ventral view the base is hidden by the occular and antennary segments. In the adult the antero-lateral spines, Plate 13, *e*, are quite small, and all the others are wanting, unless a movable plate, *r*, represents the rostrum. The antero-lateral margins now meet at an angle of 180° and form the anterior face of the carapace. The lateral margins are nearly straight, and diverge from each other a little; and the postero-lateral angles, *f*, are now rounded.

THE SEGMENTS.

The time of appearance of the various segments and their appendages is shown in the accompanying table, pages 160 and 161, in which

APPENDAGES OF ADULTS.	NUMBER OF SEGMENT.	FIRST STAGE.	SECOND STAGE.
Eyes.	1	Appendages present, segments fused.	Same as in first Stage.
1st Antennae.	2		
2d Antennae.	3		
Mandibles.	4		
1st Maxillae.	5		
2d Maxillae.	6		
Oral Palpus, or *1st Maxilliped.*	7	Distinct.	Same as in first stage.
Grasping Hand, or *2d Maxilliped.*	8	Distinct.	Same as in first stage.
1st Oral Hand, or *3d Maxilliped.*	9	Segments distinct, but without appendages	Same as in first stage.
2d Oral Hand, or *1st Pereiopod.*	10		
3d Oral Hand, or *2d Pereiopod.*	11		
1st Walking Limb, or *3d Pereiopod.*	12	Represented by an unsegmented region.	Segments distinct without appendages.
2d Walking Limb, or *4th Pereiopod.*	13		
3d Walking Limb, or *5th Pereiopod.*	14		
1st Swimming Foot.	15	Segments distinct, with appendages.	Same as in first stage.
2d Swimming Foot.	16		
3d Swimming Foot.	17		
4th Swimming Foot.	18		
5th Swimming Foot.	19	Distinct without appendages.	Same as in first stage.
Swimmeret.	20	Fused.	Same as in first stage.
Telson.	21		

Number of Segment.	Third Stage.	Fourth Stage.	Adult.
1	Segment distinct.	Same as in third stage.	Same as in third stage.
2	Same as in first stage.	Segment distinct.	Same as in fourth stage.
3		Same as in first stage.	Segment distinct.
4			Same as in first stage.
5			
6			
7	Same as in first stage.	Same as in first stage.	Same as in first stage.
8	Same as in first stage.	Same as in first stage.	Same as in first stage.
9	Appendages present as buds. Segments distinct.	Segments fused, limbs bending forward and chelate.	Same as in fourth stage.
10			
11			
12		Appendages present, segments distinct.	Same as in fourth stage.
13			
14			
15	Appendages present.	Same as in third stage	Same as in fourth stage.
16			
17			
18			
19			
20	Segment represented by its ganglion.	Segment and appendages present.	
21		Telson.	Same as in fourth stage.

the first column describes in ordinary type, the function of the appendage of the adult, and also gives in italics the corresponding appendages of an ordinary Decapod; the second gives the number of the segment, counting from the anterior end of the body of the adult; the third, the condition of the segment and its appendages, at the stage shown in Plate 1, Figure 1; the fourth, their condition at the stage shown in Plate 1, Figure 3; the fifth, their condition at the stage of Plate 2; the sixth, their condition at the stage shown in Plate 3, Figure 1, and the seventh, their condition in the adult. In the drawings the segments are indicated by figures, their appendages by figures with an *, and their ganglia by figures with an accent.

From this table it will be seen that the free segments make their appearance in the following order, the antennary segment being the last: 9th, 10th, 11th, 15th, 16th, 17th, 18th, 19th, 12th, 13th, 14th, 1st, 20th, 21st, 2d, 3d; and it will also be seen that all the segments, except those which carry the mandibles and first and second maxillae, that is the 4th, 5th and 6th, are at some stage of development free from the carapace. As there is no reason to doubt that the carapace of Squilla is homologous with that of the Decapod zoea, and this again with that of the adult, the view that the Decapod carapace represents the terga of all the segments of the cephalothorax is clearly untenable.

THE APPENDAGES.

The eyes, 1, are substantially like those of the adult, from the earliest stages.

The antennules. During the first and second stages the antennules, 2, are almost as long as the rostrum, and consist of a based three-jointed protopodite, which carries a short thick exopodite, *b*, with three setae at its tip, and a more slender endopodite, *a*, with two terminal setae. On the dorsal surface of the proximal end of the basal joint of the prodopodite is the spherical auditory sac, shown in the dorsal view, Figure 2. In the third stage, Plate 10, the exopodite, *b*, is divided into a very small terminal joint with one seta, and a long swollen joint with five; while the endopodite, *a*, is divided into three joints, each of which carries a seta. At this stage the antennules are much shorter than the rostrum. In the fourth stage, Plate 11, Figure 1, the antennules are longer than the rostrum; the exopodite is divided into two branches; the organ is carried upon a distinct segment, and is substantially like that of the adult.

The antennae. In the first stage, Plate 1, Figure 2, this, 3*, consists of a three-jointed stem, with a terminal scale, which bears a few setae. In the fourth stage, Plate 11, Figure 1, the scale is large,

fringed with stout setae, and a three-jointed flagellum, *s*, springs from the suture between the first and second joints of the stem. The differences between this stage and the adult, will be seen by a comparison with Plate 12.

The mouth parts were not carefully studied, but three pairs, 4, 5, 6, and an upper lip, *n*, were present at all stages.

The oral palpi. These appendages are relatively much longer, Plate 9, Figures 1 and 2, 7, and much more movable at an early stage than in the adult; they consist of a long slender four-jointed stem, and a terminal joint furnished with hairs. During the earlier stages this terminal portion is only slightly bent upon the stem, but in the third and fourth stages, Plates 10 and 11, 7, it is so twisted as to lie parallel to the stem, and the stems themselves are now nearly straight, very slightly movable, and lie on the sides of the mouth parts, as in the adult.

The grasping legs. At the first stage these appendages, 8, have their characteristic adult form, and undergo little change. In the oldest larva which was captured, the teeth upon the terminal joint had not made their appearance. At the base of this appendage, during all the larval stages, there is a large flat membranous oval plate, *c*, which moves with the limb, and may perhaps be homologous with the gill of a Decapod.

The oral hands. These appendages are acquired between the stages shown in Plates 10 and 11. At first they project at right angles to the body, but they soon twist forwards over the mouth, and their basal joints become crowded together as in the adult. Each of them is furnished with a small gill-like plate, Plate 11, Figure 2, *c'*, *c''*, *c'''*, like that upon the basal joint of the grasping hand.

The three pairs of walking limbs appear soon after the oral hands, and consist of a protopodite, an exopodite and an endopodite, as in the adult.

The abdominal appendages have substantially the adult form, from the time of their first appearance, and consist of a protopodite which is long and narrow in the earlier stages, and short and wide in the adult; a scale like oval exopodite which has a fringe of a few stiff setae in the younger stages, and numerous flexible setae in the adult. The endopodite is very similar in shape, but carries on its inner margin, during the later stages, a second small joint, which in the adult, is in contact, on the median line, with the corresponding part of the endopodite of the other side of the body.

THE TELSON

Is at first, Plate 9, Figure 1, 20, 21, elongated, nearly rectangular, and nearly twice as long as

wide. Its posterior margin is serrated, and slightly concave. In the next stage, Plate 9, Figure 3, it is oval, about one-third longer than wide, and the posterior margin is deeply concave. In the third stage, Plate 10, it is octagonal, almost as wide as long, and its angles carry prominent teeth, which point backwards. The serrated posterior margin is still concave, and regularly curved.

In the next stage, Plate 11, Figure 1, the anterior portion of the telson has separated as the sixth abdominal segment, 20. The true telson, 21, is now about as wide as long, ten sided, and the angles are toothed. The posterior margin is notched in the centre, and consists of two straight serrated edges, meeting at an acute angle. The postero-lateral edges are also serrated. The characteristics of the adult telson are sufficiently well shown in Plate 13, 21.

THE NERVOUS SYSTEM.

In the first stage the optic ganglia form a large rounded body, Plate 9, Figure 1, 1′, imperfectly divided posteriorly into two lobes, by a longitudinal furrow, which runs forwards, about half way to the anterior margin of the mass. The two ganglia of the antennules, 2′, are entirely

separated on the median line by the furrow, but are in contact with each other; well marked furrows separate them from the optic ganglia.

From the posterior margins of these ganglia a pair of very thick commissures, *g*, pass backwards, diverging from each other, and forming the sides of a large oval foramen, *h*. The ganglia of all the segments, from the 1st maxillae to the last pair of walking legs, 5 to 14, are represented by a long rod-like body on the median line, with its anterior end divided into eight ganglia, and the posterior portion undivided.

This rod is not divided into halves, but is continuous across the median line. The first of the ganglia is very small, while the second, that of the second maxillae, Figure 1, 6′, is very much larger, the third, that of the oral palpi, 7′, still larger, and the others about equal in size. In the mid-body the number of constrictions upon the nerve-rod is one greater than the number upon the surface of the body, and the ganglion of the 12th segment, 12′, accordingly appears before the segment itself. In the abdomen there are five sharply defined ganglia, 15′ to 19′, one for each segment, and they are widely separated from each other, and connected by double commissures.

In the next stage, Plate 9, Figure 3, the cerebrum has undergone considerable change, and

now consist of a single anterior rounded mass, 1′, the optic ganglia, and two posterior portions, separated on the median line, with a slight constriction dividing them into an anterior antennulary ganglion, 2′, and a posterior antennary ganglion, 3′, which is sharply separated from the commissure, which is now a small thread-like fibre. Each of the segments of the mid-body is now furnished with a ganglion, 9′ to 14′, but they are still crowded together and without commissures.

In the next stage, Plate 10, the ganglia of the 12th, 13th and 14th segments are separated from each other, spherical, and connected by short double commissures. The ganglion of the sixth abdominal segment, 20′, is present, but not the segment itself. The commissures between the abdominal ganglia are much longer than at an earlier stage.

In the next stage the ganglia of the 7th to 11th segments, Plate 11, Figures 1 and 2, 7′ to 11′, are crowded together, and form a compact thoracic mass, as in the adult. The ganglia of all the succeeding segments, 14′ to 20′, are compact, widely separated and connected by long slender double commissures, and the nervous system now has its adult form.

EXPLANATION OF THE FIGURES.

PLATE 9.

FIGURE 1.—Ventral view of youngest stage observed, magnified 75 diameters.

FIGURE 2.—Dorsal view of another larva in the same stage.

FIGURE 3.—Ventral view of an older larva.

1 to 21. Segments and appendages.
1′ to 19′. Ganglia.
a. Endopodite of antennule.
b. Exopodite of antennule.
c. Gill-like plate upon basal joint of Grasping Hand.
d. Rostrum.
e. Antero-lateral spines of carapace.
f. Postero-lateral spines of carapace.
g. Œsophageal nerve commissure.
h. Its foramen.
l. Dorsal spine of carapace.
k. Stomach.

PLATE 10.

A somewhat older larva, magnified 75 diameters; ventral view.

1 to 21. Segments.
1* to 19*. Appendages.
1′ to 20′. Ganglia.

The small letters of reference as before.

PLATE 11.

FIGURE 1.—Still older larva, viewed from the ventral surface, and magnified 30 diameters.

FIGURE 2.—Basal joints and ganglia of the appendages from the 7th to the 11th segments, magnified 75 diameters.

FIGURE 3.—Anterior end of carapace with proximal ends of appendages, magnified 75 diameters.

The letters and figures of reference are the same as in Plate 10.

PLATE 12.

Ventral view of adult.

PLATE 13.

Dorsal view of adult.

o. Optic segment.
p. Antennulary segment.
q. Antennary segment.
br. Gills.
t. Exopodite of swimmeret.
u. Spine of swimmeret.
v. Endopodite of swimmeret.
w. Anus.

The other letters and figures as in Plate 10.

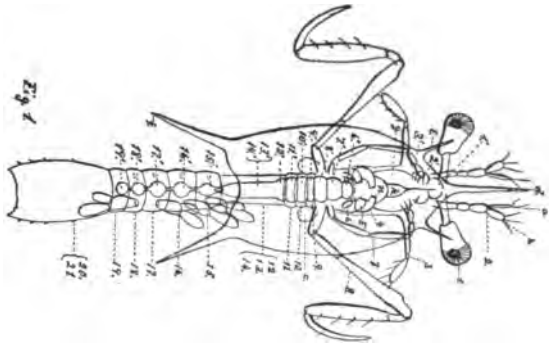


Fig. 7

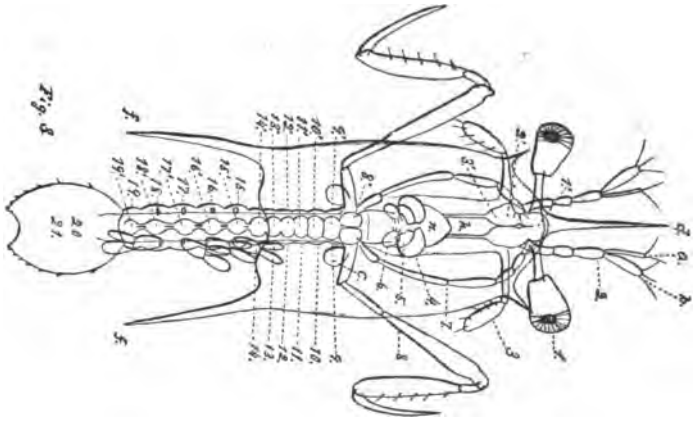


Fig. 8

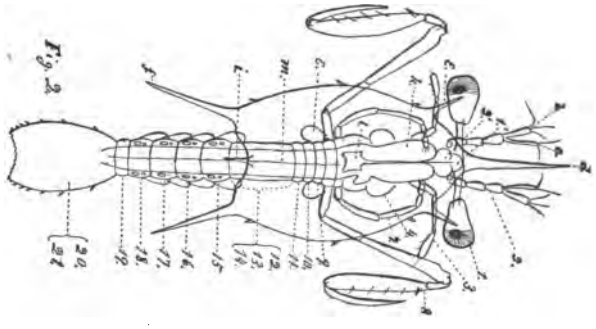


Fig. 9

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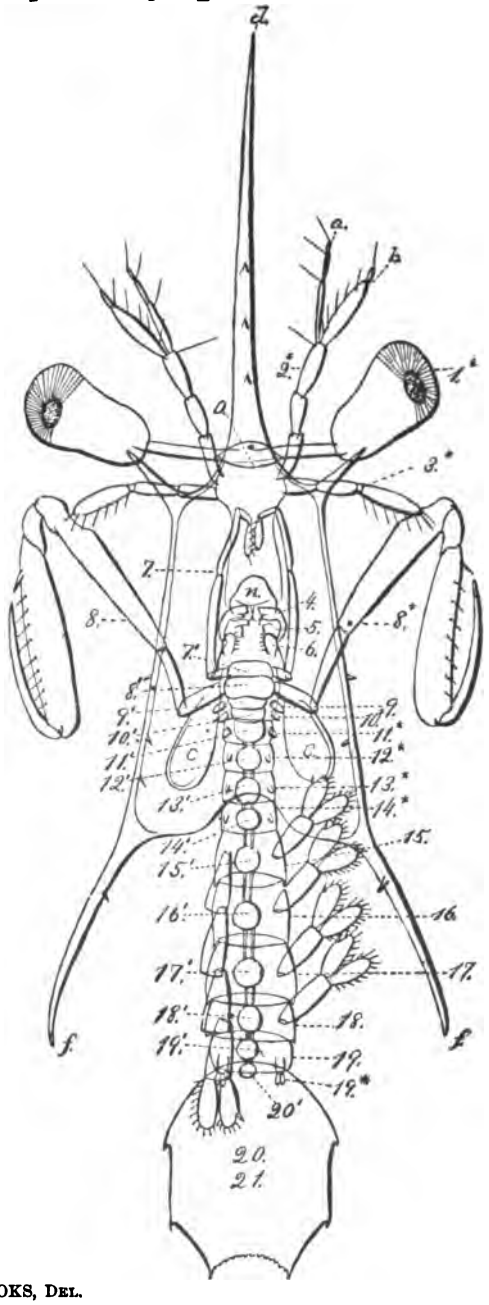

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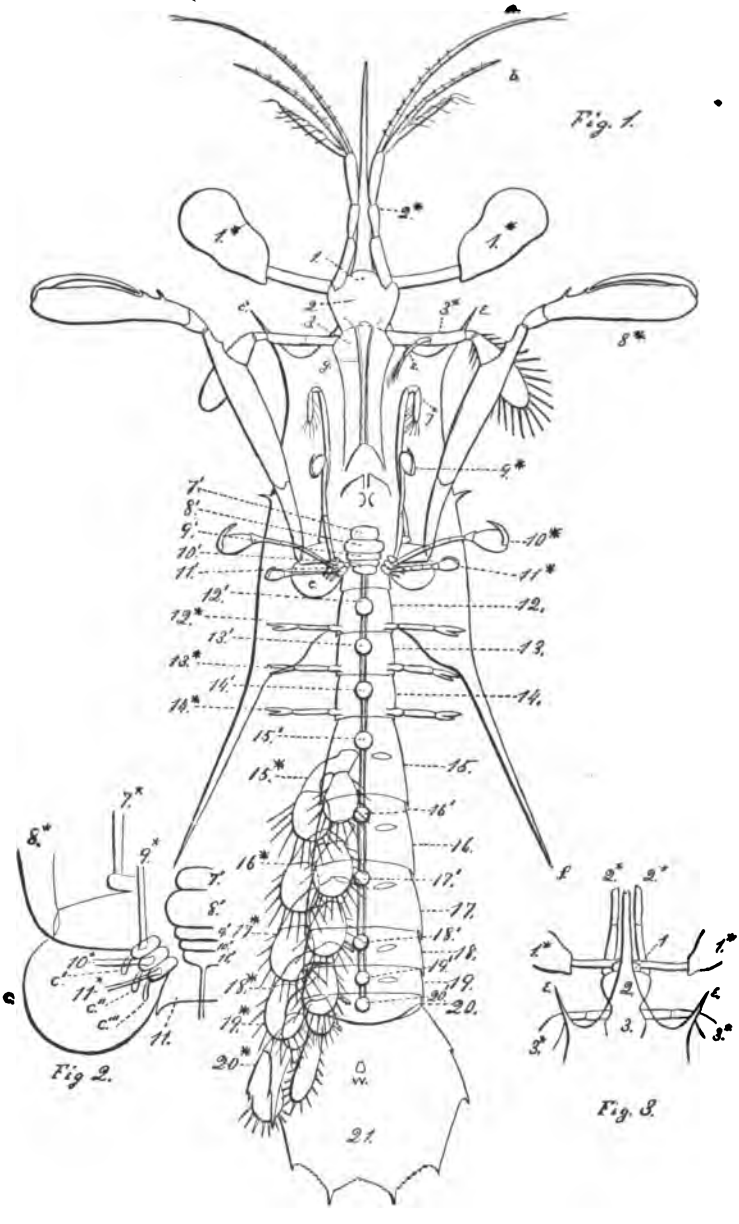
Fig. 1.
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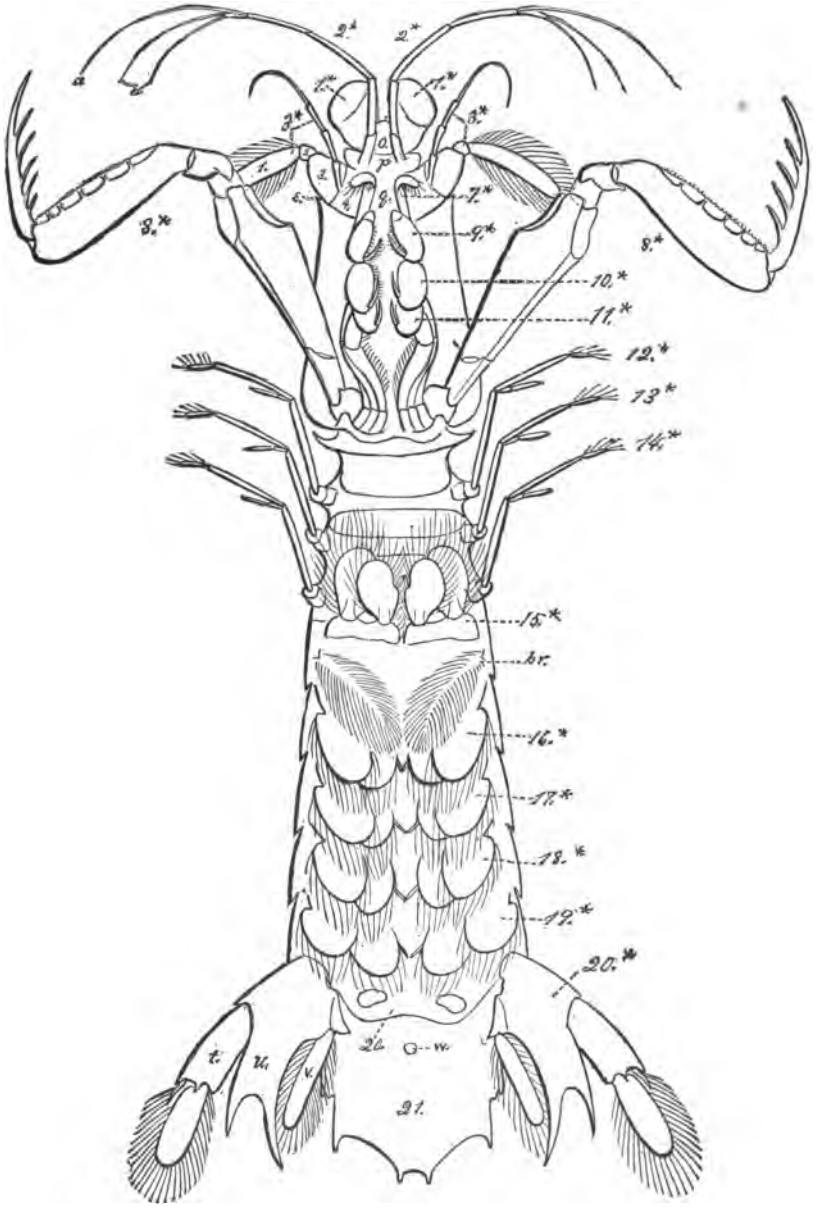

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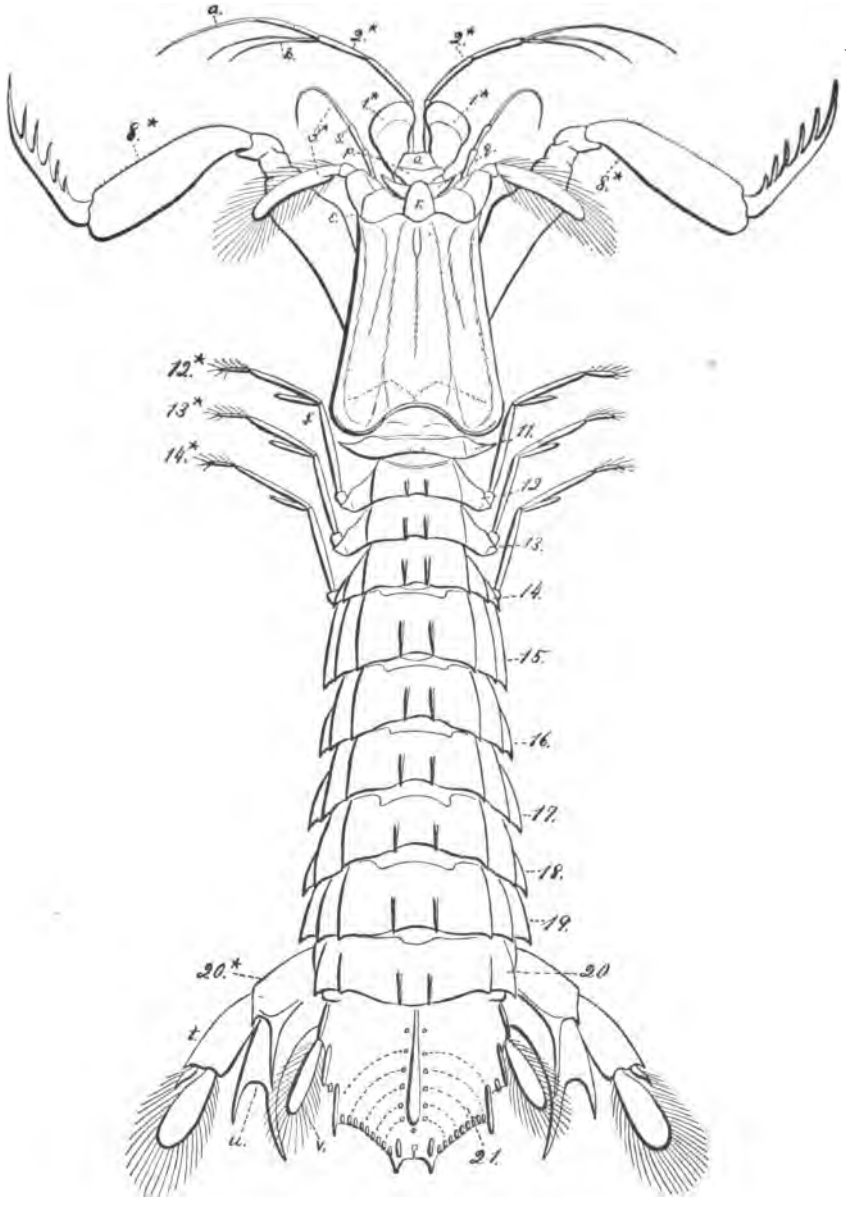

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